Chapter VII: Benefit-Cost Analysis

This chapter reports EPA's analysis of the economic benefits of the final Tier 2/Gasoline Sulfur rulemaking reducing air pollution from mobile sources. EPA is required by Executive Order 12866 to estimate the benefits of major new pollution control regulations. The analysis presented here attempts to answer three questions: 1) what are the physical effects of changes in ambient air quality resulting from reductions in NOx and SO_2 emissions?; 2) how much are the changes in air quality worth to U.S. citizens as a whole in monetary terms?; and 3) how do the benefits compare to the costs? It constitutes one part of EPA's thorough examination of all aspects of the relative merits of regulatory alternatives.

The BCA that we performed for our final rule can be thought of as having four parts, each of which will be discussed separately in the Sections that follow. These four steps are:

1. Calculation of the impact that our proposed standards will have on the nationwide inventories for NOx, NMHC, SO_2, and PM.

2. Air quality modeling to determine the changes in ambient concentrations of ozone and particulate matter (PM) that will result from our proposed standards.

3. A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the changes in ambient concentrations of various pollutants.

4. Calculation of the costs of the standards for purposes of comparison to the monetized benefits.

EPA has used the best available information and tools of analysis to quantify the expected changes in public health and environment and the economic benefits of the final Tier 2/Gasoline Sulfur rule, given the constraints on time and resources available for the analysis. We have attempted to be as clear as possible in presenting our assumptions, sources of data, and sources of potential uncertainty in the analysis. We urge the reader to particularly pay attention to the fact that not all the benefits of the rule can be estimated with sufficient reliability to be quantified and included in monetary terms. The omission of these items from the total of monetary benefits reflects our inability to measure them. It does not indicate their lack of importance in the consideration of the benefits of this rulemaking. When it is possible to qualitatively characterize a benefits category, we provide a discussion, although the benefit is not included in the estimate of total benefits.

We use the term benefits to refer to any and all positive effects of emissions changes on social welfare that we expect to result from the final rule. We use the term environmental costs (also commonly referred to as “disbenefits”) to refer to any and all negative effects of emissions changes in social welfare that result from the final rule. Where it is possible to quantify benefits and environmental costs, our measures are those associated with economic surplus in accepted applications of welfare economics. They measure value by estimating (primarily through benefits transfer) the willingness of the affected population to pay for changes in environmental quality and associated health and welfare effects.

This analysis presents estimates of the potential benefits from the Tier 2/Gasoline Sulfur rule occurring in 2030. The emissions reductions that will result from the Tier 2/Gasoline Sulfur rule have of course not actually occurred yet. The actual changes in human health and welfare outcomes to which economic values are ascribed are predictions. These predictions are based on the best available scientific evidence and judgment, but there is unavoidable uncertainty associated with each step in the complex process between regulation and specific health and welfare outcomes. The ways in which we deal with these uncertainties are discussed in Section C.

Figure VII-1 illustrates the steps necessary to link the Tier 2/Gasoline Sulfur rule with economic measures of benefits. The first two steps involve the specification and implementation of the regulation. First, the specific standards for reducing air pollution from mobile sources are established. Next, the necessary changes in vehicle technology and fuels are determined (see Chapters IV and V). The changes in pollutant emissions resulting from the hypothesized vehicle and fuel changes are then calculated for input into an air quality model, along with predictions of emissions for other industrial sectors in the baseline. Next, the predicted emissions are used as inputs to air quality models that predict ambient concentrations of pollutants over time and space. These concentrations depend on climatic conditions and complex chemical interactions. We have used the best available air quality models to estimate the changes in ambient concentrations (from baseline levels) that are used as the basis for this benefits analysis.

The predicted changes in ambient air quality then serve as inputs into functions to predict changes in health and welfare outcomes. We use the term “endpoints” to refer to specific effects that can be associated with changes in air quality. Table VII-1 lists the human health and welfare effects identified for ozone, PM, CO, and hazardous air pollutants (HAP). This list includes both those effects quantified (and/or monetized) in this analysis and those for which we are unable to provide quantified estimates. All of the effects related to CO and HAPs are not quantified for this analysis due to a lack of appropriate air quality models for these pollutants. For changes in risks to human health from ozone and PM, quantified endpoints include changes in mortality and in a number of pollution-related non-fatal health effects. To estimate these endpoints, EPA combines changes in ambient air quality levels with clinical and epidemiological evidence about population health response to pollution exposure. For welfare effects, the endpoints are defined in terms of levels of physical damage (for materials damage), economic output (agriculture and forestry),

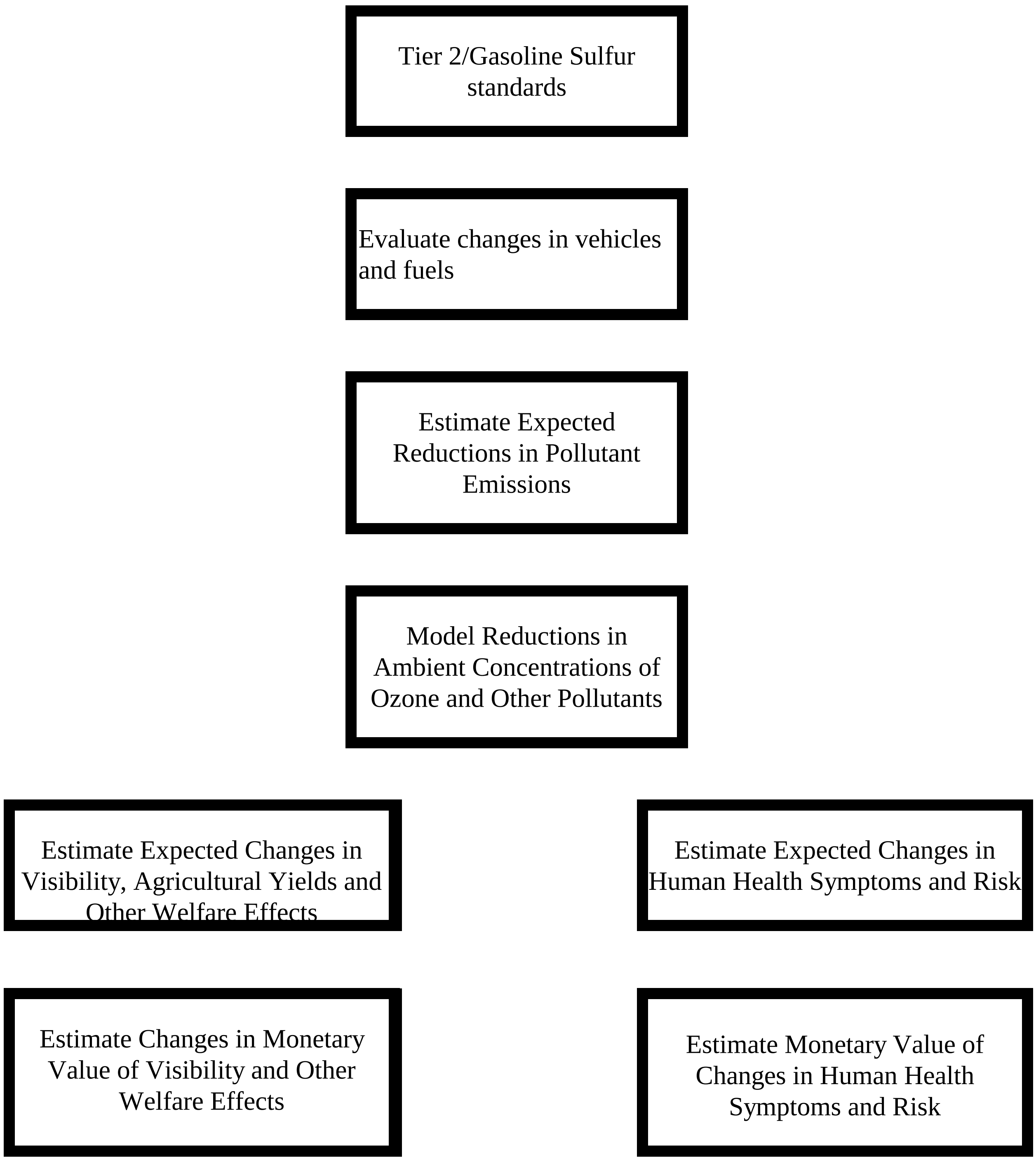

Figure VII-1
Steps in the Tier 2/Gasoline Sulfur Benefits Analysis

Table VII-1. Human Health and Welfare Effects of Pollutants Affected by the Tier 2/Gasoline Sulfur Rule

Pollutant	Primary Quantified and Monetized Effects	Alternative Quantified and/or Monetized Effects	Unquantified Effects
Ozone Health	Chronic asthma[a] Minor restricted activity days/acute respiratory symptoms Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma		Premature mortality[b] Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Non-asthma respiratory emergency room visits
Ozone Welfare	Decreased worker productivity Decreased yields for commercial crops		Decreased yields for commercial forests Decreased yields for fruits and vegetables Decreased yields for non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions
PM Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Lower and upper respiratory illness Shortness of breath Minor restricted activity days/acute respiratory symptoms Work loss days		Infant mortality Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits
PM Welfare	Visibility in California, Southwestern, and Southeastern Class I areas	Visibility in Northeastern, Northwestern, and Midwestern Class I areas	
Nitrogen and		Costs of nitrogen controls to reduce	Impacts of acidic sulfate and nitrate deposition on

Pollutant	Primary Quantified and Monetized Effects	Alternative Quantified and/or Monetized Effects	Unquantified Effects
CO Health			Premature mortality[b] Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina Non-asthma respiratory ER visits
HAPS Health			Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde)
HAPS Welfare			Direct toxic effects to animals Bioaccumlation in the food chain

[a] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, a recent epidemiological study shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in some non-smoking men, but not in women.

[b] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants.

light transmission (for visibility), and increases in terrestrial and estuarine nutrient loading (for ecological effects).

As with emissions and air quality estimates, EPA's estimates of the effect of ambient pollution levels on all of these endpoints represent the best science available to the Agency. The majority of the analytical assumptions used to develop our estimates have been reviewed and approved by the EPA Science Advisory Board. However, like all estimates, they also contain unavoidable uncertainty, as does any prediction of the future. In Section C and in the subsections on health and welfare endpoints, this uncertainty is discussed and characterized.

This chapter proceeds as follows: Sections A and B summarize emissions and air quality results and discuss the way that emissions and air quality changes are used as inputs to the benefits analysis. Section C introduces the kinds of benefits that are estimated, presents the techniques that are used, and provides a discussion of how we incorporate uncertainty into our analysis. In Section D, we describe individual health effects and report the results of the analysis for human health effects. In Section E, we describe individual welfare effects and report the results of the analysis for welfare effects. Section F reports our estimates of total monetized benefits and alternative calculations. Finally, Section G presents a comparison of monetized benefits and costs.

A. Emissions

In order to determine the air quality impact of the Tier 2 program, we first calculated the reductions in vehicle emissions that are expected to occur as a result of those standards, and then determined the impact of those emission reductions on the nationwide[1] inventories for NOx, NMHC, SO2, and PM. This Section describes how these inventory impacts were determined.

At proposal, we evaluated the impact of the Tier 2 program using a 1990 emissions inventory from the CAA Section 812 study (Ref.), and considered the effect of full-fleet turnover that was expected to occur well into the future on populations estimated for 2010. This approach to the analysis was necessary because at the time of proposal, we had no available baseline data set beyond the year 2010, since the Section 812 inventory was developed only for this year. The analysis at proposal, therefore, made adjustments to allow the use of 2010 as a surrogate for a future year in which the fleet consists entirely of Tier 2 vehicles. For the final rule's analysis, we have enhanced the analysis significantly. We updated the emissions inventory to reflect new CAA programs and changes in inventories through the year 1996. We then evaluated the impact

[1] For the purposes of air quality modeling, 'nationwide' is taken to mean the contiguous 48-states. Also, the proposed Tier 2/gasoline sulfur standards are assumed to have no effect on vehicle emissions in California, though air quality in California may be affected through meteorological boundary conditions.

of the program in 2030 and on 2030 populations.

The inventories developed for our air quality assessment and for the benefit-cost analysis have already been presented and discussed in Chapter III and in the supporting documents referenced in that chapter. Interested readers desiring more information about the inventory methodologies or results should consult that chapter for details.

The Tier 2/gasoline sulfur program has various emission-related components which begin at various times and in some cases phase in over time. This means that during the early years of the program there will not be a consistent match between costs and benefits. This is due to the fact that the full vehicle cost is incurred at the time of vehicle purchase, while the fuel cost along with the emission reductions and benefits occur throughout the lifetime of the vehicle. Because of this inconsistency and our desire to more appropriately match the costs and emission reductions of our proposed program, our analysis uses a future year when the fleet is nearly fully turned over. For today's rule this stability does not occur until well into the future. For the purpose of the benefit calculations, we assume that 2030 is a representative year to consider in comparison with the costs.

The resulting analysis represents a snapshot of benefits and costs in a future year in which the light-duty fleet consists almost entirely of Tier 2 vehicles. As such, it depicts the maximum emission reductions (and resultant benefits) and among the lowest costs that would be achieved in any one year by the program on a "per mile" basis. (Note, however, that net benefits would continue to grow over time beyond those resulting from this analysis because of growth in vehicle miles traveled and population.) Thus, based on the long-term costs for a fully turned over fleet, the resulting benefit-cost ratio will be close to its maximum point (for those benefits which we have been able to value).

B. Air Quality Impacts

In Chapter III, we described the Tier 2 program's impact on air quality in 2007. The 2007 analysis shows the initial impact of the rule on area that must attain the NAAQS by 2007. Using this information the Agency provides its justification for the need for the rule. For purposes of the benefit-cost analysis, EPA prepared a second air quality analysis to evaluate the impact of the rule after it is fully implemented (i.e., when all on-highway vehicles are expected to be compliant with the new Tier 2 controls). We chose 2030 as this analytical year reflecting full-fleet turnover and, thus, all costs are realized as well as most benefits.[2]

This section summarizes the methods for and results of estimating air quality for the 2030

[2] We recognize that program costs and benefits will continue to accrue as new vehicles are purchased.

base case and Tier 2 control scenario. EPA has focused on the air quality changes that have been linked to health, welfare, and ecological effects. These air quality changes include the following:

- Ambient ozone–as estimated using a regional-scale version of the Urban Airshed Model (UAM-V),

- Ambient particulate matter (PM_{10} and $PM_{2.5}$)–as projected from a Source-Receptor Matrix (S-R Matrix) based on the Climatological Regional Dispersion Model (CRDM),

- Airborne nitrogen deposition–as predicted using local and regional coefficients of nitrogen deposition for selected estuaries from the Regional Acid Deposition Model (RADM) in combination with modeled reduction in NOx emissions, and

- Visibility degradation (i.e., regional haze), as developed using empirical estimates of light extinction coefficients and efficiencies in combination with modeled reductions in pollutant concentrations.

The air quality estimates in this section are based on the emission changes discussed in Section A. Using the methods identified and described in Section C, the air quality impacts listed above are then associated with human populations and ecosystems to estimate changes in health and welfare effects.

The air quality analysis used in the benefits estimation at proposal was based on results from the UAM-V and S-R Matrix models to estimate 1990 baseline and 2010 base case air quality for ozone and particulate matter, respectively. We then applied the Tier 2 control scenario to the 2010 estimates to derive the associated air quality changes. For the final rule's analysis, we updated all aspects of the analysis by estimating 1996 baseline (rather than 1990) and 2030 base case air quality (rather than using 2010 as a surrogate for full-implementation of the program). We applied the same Tier 2 control scenario (i.e., same level of stringency and control) as was used at proposal and evaluated the impact on 2030 air quality (using 2030 VMT and population projections). These updates to the analysis have augmented the preliminary benefit-cost analysis provided at proposal.

Section VII.B.1 describes the estimation of ozone air quality using UAM-V, while Section VII.B.2 covers the estimation of PM air quality using the CRDM S-R Matrix. Section VII.B.3 discusses the estimation of nitrogen deposition. Lastly, Section VII.B.4 covers the estimation of visibility degradation.

1. Ozone Air Quality Estimates

We use the previously described emissions inputs with a regional-scale version of UAM-V to estimate ozone air quality. UAM-V is an "eulerian" three-dimensional grid photochemical air quality model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is useful for evaluating the impacts of the Tier 2 rule on U.S. ozone concentrations.[3] Our analysis applies the modeling system for a base-year of 1996 and for two future-year scenarios: a 2030 base case and a 2030 Tier 2 control scenario. As discussed later, we use the two separate years because ambient air quality observations from 1996 are used to calibrate the model. These results are used solely in the benefits analysis and are not used as part of the justification for the rule. A 2007-based analysis described in Chapter III is used for that purpose.

The UAM-V modeling system requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, day-specific emissions estimates and meteorological fields, initial and boundary conditions, and land-use information. The model divides the continental United States into two regions: East and West. It then segments the area in each region into square blocks called grids (roughly equal in size to counties), each of which has several layers of air conditions that are considered in the analysis. Using this data, the UAM-V model generates predictions of hourly ozone concentrations for every grid. We then calibrate the results of this process to develop 2030 ozone profiles at monitor sites by normalizing the observations to the actual 1996 ozone data at each monitor site. For areas (grids) without ozone monitoring data, we interpolated ozone values using data from monitors surrounding the area. After completing this process, we calculated daily and seasonal ozone metrics as inputs to the health and welfare concentration-response (C-R) functions of the benefits analysis. The following sections provide a more detailed discussion of each of the steps in this evaluation and a summary of the results.

a. Modeling Domain

The modeling domain representing the eastern U.S. is the same as that used in EPA's "Regulatory Impact Analysis for the NO_x SIP Call, FIP, and Section 126 Petitions" (EPA, 1998b). As shown in Figure VII-2, this domain encompasses most of the eastern U.S. from the east-coast to mid-Texas and consists of two grids with differing resolutions. The shaded area of Figure VII-2 uses a relatively fine grid of 12 km consisting of seven vertical layers. The unshaded area of Figure VII-2 has less resolution, as it uses a 36 km grid consisting of five

[3]Douglas and Iwamiya (1999) provide further information on the UAM-V modeling used in this analysis.

vertical layers. The vertical height of the modeling domain is 4,000 meters above ground level, for both the shaded and unshaded regions.

The modeling domain used to obtain results for the western U.S. comprises the entire contiguous 48 states. Even though the modeling domain covers the entire United States, the modeling results are only used for benefit analysis of western U.S. locations (i.e., within the region not shown in Figure VII-2). The domain extends from 126 degrees west longitude to 66 degrees west longitude, and from 24 degrees north latitude to 52 degrees north latitude. The analysis used a grid cell size of approximately 56 km (or 2/3 longitude by ½ latitude) resulting in a 90 by 56 grid for each vertical layer, with eight vertical layers in all. The smaller 36 km and 12 km resolution for the eastern U.S. runs better capture the photochemical processes for that region.

b. Simulation Periods

A simulation period, or episode, consists of meteorological data characterized over a block of days that are used as inputs to the air quality model. A simulation period is selected to characterize a variety of ozone conditions including some days with high ozone concentrations in one or more portions of the U.S. and observed exceedances of the 1-hour NAAQS for ozone being recorded at monitors. This study used four multi-day simulation periods to prepare the future-year ozone profiles. For the eastern U.S. ozone analysis, we modeled two simulation periods: July 12-24 and July 5-15, 1995. For the western U.S. analysis, the simulation periods were July 5-15 and July 18-31, 1996. These episodes include a 2-3 day "ramp-up" period to initialize the model, but the results for these days are not used in this analysis.

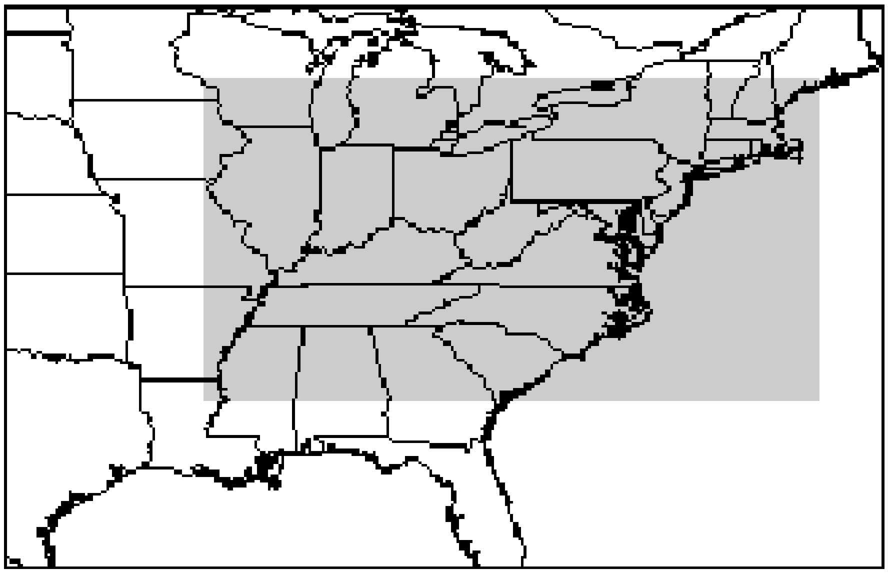

Figure VII-2. UAM-V Modeling Domain for Eastern U.S.

c. Converting UAM-V Outputs to Full-Season Profiles for Benefits Analysis

This study extracted hourly, surface-layer ozone concentrations for each grid-cell from the standard UAM-V output file containing hourly average ozone values. These model predictions are used in conjunction with the observed concentrations as obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[4,5] The predicted changes in ozone concentrations from the 2030 basecase to 2030 policy scenario serve as inputs to the health and welfare concentration-response (C-R) functions of the benefits analysis, i.e., the Criteria Air Pollutant Modeling System (CAPMS). In order to estimate ozone-related health and welfare effects for the entire United States, full-season ozone data is required for every CAPMS grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in the contiguous 48 states in two steps: (1) we combine monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of eight km by eight km population grid-cells, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily average [6,7] For the analysis of ozone impacts on agriculture, we use a similar approach except air quality is interpolated to county centroids as opposed to population grid-cells. Each approach is fully detailed in Abt Associates (1999).

d. Ozone Air Quality Results

Table VII-2 provides a summary of the predicted ambient ozone concentrations from the UAM-V model for the 2030 base case and changes associated with Tier 2 control scenario. As shown, the mean seasonal average ozone concentrations across all U.S. population grid-cells declines by almost 2 percent, or 0.6 ppb. A similar relative decline is predicted for the population-weighted average, which indicates rather uniform reductions in these concentrations across urban and rural areas. The impact of Tier 2 on seasonal SUM06 ozone metric are significantly greater with the average across all U.S. counties declining by almost 26 percent, or

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[4] The ozone season for this analysis is defined as the 5-month period from May to September; however, to estimate certain crop yield benefits the modeling results were extended to include months outside the 5-month ozone season.

[5] Based on AIRS, there were 949 ozone monitors with sufficient data, i.e., at least 9 hourly observations per day (8 am to 8 pm) in a given season.

[6] The 8 km grid squares contain the population data used in the health benefits analysis model, CAPMS. See Section C of this chapter for a discussion of this model.

[7] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (VNA) spatial interpolation (See Abt Associates (1999) for a more detailed description).

2.2 ppb. Alternatively, although the absolute change predicted for the population-weighted is similar to that for the simple average (i.e., 2.4 ppb versus 2.2 ppb), the relative change is less at 12.4 percent because of higher observed baseline values for this ozone metric.

Table VII-2. Summary of UAM-V Derived Hourly Ozone Air Quality for 2030 Base Case and Change Due to Tier 2 Standards

Statistic [a]	*2030 Base Case*	*Change* [b]	*Percent Change* [b]
Seasonal Average (ppb)			
Minimum [c]	11.98	-0.51	-4.26%
Maximum [c]	77.23	-0.16	-0.20%
Average	29.85	-0.59	1.98%
Median	29.45	-0.50	-1.69%
Population-Weighted Average [d]	29.80	-0.47	1.57%
Seasonal SUM06 (ppb)			
Minimum [c]	0.00	0.00	0.00%
Maximum [c]	118.58	-9.72	-8.20%
Average	8.31	-2.20	-26.48%
Median	4.97	-2.33	-46.88%
Population-Weighted Average [d]	19.60	-2.44	-12.43%

[a] The seasonal average and SUM06 are calculated at the CAPMS gridcell level and at the county level, respectively. There are at two levels since health effects estimates are generated at each CAPMS gridcell, and agricultural benefits (which require SUM06) are generated at the county level. Both ozone measures are based on the results of enhanced spatial interpolation. The seasonal average is the average over all hours in May through September. SUM06 is defined as the cumulative sum of hourly ozone concentrations over 0.06 ppb that occur during daylight hours (from 8am to 8pm) in the months of May through September.

[b] The change is defined as the control case value minus the base case value. The percent change is the "Change" divided by the "2030 Base Case."

[c] The base case minimum (maximum) is the value for the CAPMS gridcell with the lowest (highest) seasonal average.

[d] Calculated by summing the product of the projected 2030 CAPMS gridcell population and the estimated 2030 CAPMS gridcell seasonal ozone concentration, and then dividing by the total population. The SUM06 estimates are calculated analogously at the county level.

2. PM Air Quality Estimates

EPA used the previously described emissions inputs with a national-scale S-R Matrix based on CRDM to evaluate the effects of the Tier 2 rule on ambient concentrations of both PM_{10} and $PM_{2.5}$. Ambient concentrations of PM are composed of directly emitted particles and of secondary aerosols of sulfate, nitrate, ammonium, and organics. Relative to more sophisticated and resource-intensive three-dimensional modeling approaches, the CRDM and its associated S-R Matrix do not fully account for all the complex chemical interactions that take place in the atmosphere in the secondary formation of PM. Instead it relies on more simplistic species dispersion–transport mechanisms supplemented with chemical conversion at the receptor location.

The S-R Matrix consists of fixed-coefficients that reflect the relationship between annual average PM concentration values at a single receptor in each county (i.e., a hypothetical monitor sited at the county population centroid) and the contribution by PM species to this concentration from each emission source (E.H. Pechan, 1996). The modeled receptors include all U.S. county centroids as well as receptors in 10 Canadian provinces and 29 Mexican cities/states. The methodology used in this RIA for estimating PM air quality concentrations is detailed in Pechan-Avanti (1999) and is similar to the method used in the July 1997 PM and Ozone NAAQS RIA (U.S. EPA, 1997e) and the RIA for the final Regional Haze Rule (U.S. EPA, 1999). The following sections summarize the steps taken to apply the S-R Matrix for this analysis and to derive the resulting changes in PM air quality.

a. Development of the S-R Matrix

The S-R Matrix was developed using the CRDM, which uses assumptions similar to the Industrial Source Complex Short Term model (ISCST3), an EPA-recommended short range Gaussian dispersion model. The CRDM incorporates terms for wet and dry deposition and chemical conversion of SO_2 and NO_x to PM, and uses climatological summaries (annual average mixing heights and joint frequency distributions of wind speed and direction) from 100 upper air meteorological sites throughout North America. Meteorological data for 1990 coupled with emissions data from version 2.0 of the 1990 National Particulate Inventory (NPI) were used with CRDM to develop the S-R Matrix.

The NPI was separated into 5,944 sources (i.e., industrial point, utility, area, nonroad, and motor vehicle) of primary and precursor emissions. Each individual unit in the inventory was associated with one of four modeled source types (i.e., area, point sources with effective stack height of 0 to 250m or 250m to 500m, and individual point sources with effective stack height above 500m) for each county. Emissions that were modeled include SO_2, NO_x, and ammonia, which are needed to calculate ammonium sulfate and ammonium nitrate concentrations; VOC, which are needed to calculate secondary organic aerosols; and directly emitted PM_{10} and $PM_{2.5}$.

Both anthropogenic and natural sources of each species were included.

The resulting transfer coefficients are adjusted to account for the chemical balance between sulfate, nitric acid, and ammonium (Latimer, 1996). The coefficients for SO_2, NO_x, and ammonia were multiplied by the ratios of the molecular weights of sulfate/SO_2, nitrate/nitrogen dioxide and ammonium/ammonia to obtain concentrations of sulfate, nitrate and ammonium.[8] In the presence of sulfate and nitric acid (the gas phase oxidation product of NOx), ammonia reacts preferentially with sulfate to form particulate ammonium sulfate rather than react with nitric acid to form particulate ammonium nitrate. So, ammonium nitrate forms under conditions of excess ammonium, and only under relatively low temperatures. Accordingly, for each county receptor, the sulfate-nitrate-ammonium equilibrium is estimated based on the following simplifying assumptions:

1. All sulfate is neutralized by ammonium;
2. Ammonium nitrate forms only when there is excess ammonium;
3. Average annual particle nitrate concentrations are divided by four assuming that sufficiently low temperatures are present only one-quarter of the year.

The total particle mass of ammonium sulfate and ammonium nitrate is calculated by multiplying the anion concentrations of sulfate and nitrate by 1.375 and 1.290 respectively.

b. Fugitive Dust Adjustment Factor

As demonstrated in the RIA for the PM and Ozone NAAQS (U.S. EPA, 1997e), the 1990 CRDM predictions for fugitive dust are not consistent with measured ambient data. The CRDM-predicted average fugitive dust contribution to total $PM_{2.5}$ mass is 31 percent in the East and 32 percent in the West; however, monitoring data from the IMPROVE network show that minerals (i.e., crustal material) comprise only about five percent of $PM_{2.5}$ mass in the East and roughly 15 percent of $PM_{2.5}$ mass in the West (U.S. EPA, 1996a). These disparate results suggest a systematic overestimate in the fugitive dust contribution to total PM. This overestimate is further complicated by the recognition that the 1990 NPI significantly overestimates fugitive dust emissions. A comparison with a more recent National Emissions Trends inventory indicates that the NPI overestimates fugitive dust PM_{10} and $PM_{2.5}$ emissions by 40 percent and 73 percent respectively[9] (U.S. EPA, 1997c).

[8] Ratio of molecular weights: Sulfate/SO_2= 1.50; nitrate/nitrogen dioxide = 1.35; ammonium/ammonia = 1.06.

[9] Natural and man-made fugitive dust emissions account for 86 percent of PM_{10} emissions and 59 percent of $PM_{2.5}$ emissions in the 1997 version of the National Emission Trends Inventory.

To address this bias, we applied a multiplicative factor of 0.25 nationally to fugitive dust emissions as a reasonable first-order attempt to reconcile differences between modeled predictions of PM_{10} and $PM_{2.5}$ and actual ambient data. This adjustment results in a fugitive dust contribution to modeled ambient $PM_{2.5}$ concentrations of 10 percent to 17 percent.[10] Even after this adjustment the fugitive dust fraction of total eastern $PM_{2.5}$ mass is 10.4 percent, which is still greater than the five percent indicated by IMPROVE monitors. However, given that the adjustment factor brings the modeled fugitive dust contribution to $PM_{2.5}$ mass more within the range of values reported from monitoring data, we adjusted the fugitive dust contribution to total PM that is estimated by the S-R Matrix by this factor. This factor still may result in an overprediction of the fugitive dust contribution in some locations.

c. Normalizing S-R Matrix Results to Observed Data

In an attempt to further ensure comparability between S-R Matrix results and measured annual average PM values, we also calibrated these results to observed monitoring data using factors developed for the PM and Ozone NAAQS RIA (U.S. EPA, 1997e). For the NAAQS RIA, a "calibration factor" was developed for each monitored county based on monitoring data from 1993 to 1995 for PM_{10} from the AIRS database.[11] This calibration procedure was applied to all S-R Matrix predictions, regardless of overprediction or underprediction relative to monitored values, and equally across all particle species contributing to the annual average PM value at a county-level receptor. The PM_{10} data represent the annual average of design value monitors averaged over three years (U.S. EPA, 1997f). We eliminated the standardization for temperature and pressure from this concentration data based upon proposed revisions to the reference method for PM_{10}.[12]

[10] Using 0.25 multiplicative factor, fugitive dust as percentage of $PM_{2.5}$ mass for: Central U.S. = 17.2 percent; Eastern U.S.= 10.4 percent; Western U.S.= 10.6 percent. By comparison, without using a multiplicative factor, fugitive dust as a percentage of $PM_{2.5}$ mass for: Central U.S. = 44.6 percent; Eastern U.S. = 30.9 percent; Western U.S. = 31.5 percent.

[11] The normalization procedure was conducted for county-level modeled PM_{10} and $PM_{2.5}$ estimates falling into one of four air quality data tiers. The tiering scheme reflects increasing relaxation of data completeness criteria and therefore increasing uncertainty for the annual design value (U.S. EPA, 1997c). Nationwide, Tier 1 monitored counties cover the 504 counties with at least 50 percent data completeness and therefore have the highest level of certainty associated with the annual design value. Tier 2 monitored counties cover 100 additional counties with at least one data point (i.e., one 24-hour value) for each of the three years during the period 1993 -1995. Tier 3 monitored counties cover 107 additional counties with missing monitoring data for one or two of the three years 1993 - 1995. In total, Tiers 1, 2 and 3 cover 711 counties currently monitored for PM_{10} in the 48 contiguous states. Tier 4 covers the remaining 2369 non-monitored counties.

[12] See Appendix J - Reference Method for PM_{10} , Final Rule for National Ambient Air Quality Standards for Particulate Matter (Federal Register, Vol. 62, No. 138, p. 41, July 18, 1997).

Because there is little $PM_{2.5}$ monitoring data available, we developed a general linear model to predict $PM_{2.5}$ concentrations directly from the monitored PM_{10} values (U.S. EPA, 1996a). The analysis used a SAS™ general linear model (i.e., GLM) procedure to predict $PM_{2.5}$ values as a function of season, region, and measured PM_{10} value. We then used these derived $PM_{2.5}$ data to calibrate the S-R Matrix model predictions of annual average $PM_{2.5}$.

d. PM Air Quality Results

Table VII-3 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations from the S-R Matrix for the 2030 base case and changes associated with Tier 2 control scenario. As shown, the average annual mean concentrations of PM_{10} across all U.S. counties declines by almost 1 percent, or 0.22 g/m^3. The same relative decline is predicted for the population-weighted average for mean PM_{10}, which indicates rather uniform reductions in these concentrations across urban and rural areas. The impact of Tier 2 on $PM_{2.5}$ concentrations are slightly greater with average annual mean concentrations of $PM_{2.5}$ across all U.S. counties declining by almost 2 percent, or 0.22 g/m^3. Similar to PM_{10} concentrations, the relative change predicted for the population-weighted average does not differ much from the spatial average.

Table VII-3. Summary of 2030 Base Case PM Air Quality and Changes Due to Tier 2 Standards

Statistic	*2030 Base Case*	*Change*[a]	*Percent Change*
PM_{10}			
Minimum Annual Mean PM_{10} (g/m^3) [b]	6.64	-0.03	-0.5%
Maximum Annual Mean PM_{10} (g/m^3) [b]	145.11	-0.09	-0.1%
Average Annual Mean PM_{10} (g/m^3)	24.89	-0.22	-0.9%
Median Annual Mean PM_{10} (g/m^3)	23.90	-0.20	-0.6%
Population-Weighted Average Annual Mean PM_{10} (g/m^3) [c]	36.21	-0.31	-0.9%
$PM_{2.5}$			
Minimum Annual Mean $PM_{2.5}$ (g/m^3) [b]	0.86	0.00	0.0%
Maximum Annual Mean $PM_{2.5}$ (g/m^3) [b]	88.47	-0.08	-0.1%
Average Annual Mean $PM_{2.5}$ (g/m^3)	11.93	-0.22	-1.8%
Median Annual Mean PM_{10} (g/m^3)	11.96	-0.20	-1.7%
Population-Weighted Average Annual Mean $PM_{2.5}$ (g/m^3) [c]	15.52	-0.31	-2.0%

[a] The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case is the observed change for the county with the lowest (highest) annual average in the base case.

[c] Calculated by summing the product of the projected 2030 county population and the estimated 2030 county PM concentration, and then dividing by the total population in the 48 contiguous states.

Table VII-4 provides additional insights on the changes in PM air quality resulting from the motor vehicle Tier 2 and fuel standards. This table focuses on the absolute change (in terms of g/m^3) and relative change (in terms of percent) observed across individual U.S. counties. As shown, the absolute reduction in annual mean PM_{10} concentration ranged from a low of 0.01 g/m^3 to and high of 1.25 g/m^3, while the relative reduction ranged from a low of 0.04 percent to a high of 3.3 percent. Alternatively, for mean $PM_{2.5}$, the absolute reduction ranged from zero to 1.23 g/m^3, while the relative reduction ranged from zero to 5.4 percent.

Table VII-4. Summary of Absolute and Relative Changes in PM Air Quality Due to Tier 2 Standards

Statistic	*Absolute Change from 2030 Base Case (g/m³)* [a]	*Relative Change from 2030 Base Case (%)* [b]
PM_{10}		
Minimum	-0.01	-0.04%
Maximum	-1.25	-3.30%
Average	-0.22	-0.87%
Median	-0.20	-0.94%
Population-Weighted Average [c]	-0.31	-0.91%
$PM_{2.5}$		
Minimum	0.00	0.00%
Maximum	-1.23	-5.42%
Average	-0.22	-1.77%
Median	-0.20	-1.88%
Population-Weighted Average [c]	-0.31	-1.95%

[a] The absolute change is defined as the control case value minus the base case value for each county.

[b] The relative change is defined as the absolute change divided by the base case value, or the percentage change, for each county. The information reported in this column does not necessarily reflect the same county as is portrayed in the absolute change column.

[c] Calculated by summing the product of the projected 2030 county population and the estimated 2030 county PM absolute/relative measure of change, and then dividing by the total population in the 48 contiguous states.

3. Visibility Degradation Estimates

Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient, based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Based upon the light-extinction coefficient, we also calculated a unitless visibility index, called a "deciview," which is used in the valuation of visibility. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview.

Because the visibility benefits analysis (see Section VII.C) distinguishes between general regional visibility degradation and that particular to Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.), we separated estimates of visibility degradation into "residential" and "recreational" categories. The estimates of visibility degradation for the "recreational" category apply to Federally-designated Class I areas, while estimates for the "residential" category apply to non-Class I areas. Deciview estimates are developed from the estimated county-level changes in particulate matter generated from results of the S-R Matrix for the 2030 base case and Tier 2 control scenarios. These deciview estimates are then aggregated to one of eight regions in the case of the residential category (as defined by the underlying study) and one of six regions in the case of the recreational category (as defined by Class I Visibility Regions described in Section VII.C). More detail on this approach and results may be found in Pechan-Avanti (1999).

Table VII-5 provides a summary of the visibility degradation estimates in terms of deciviews by residential category across U.S. regions. As shown, the national improvement in residential visibility is 1 percent, or 0.23 deciviews. Predicted visibility improvements are the largest for the North Central and Northwest (both at 1.3 percent), the South Central (1.2 percent), and the Southeast (1.1percent). Smaller visibility improvements are predicted in the Southwest (0.5 percent) and the Northeast (0.5 percent).

Table VII-6 provides a summary of the visibility degradation estimates in terms of deciviews for Class I areas (i.e., recreational category) across U.S. visibility regions. As shown, the national improvement in visibility for these areas is 0.6 percent, or 0.12 deciviews. Predicted visibility improvements are the largest for the Northwest (1.4 percent), the Southeast (0.9 percent), and the Northeast/Midwest (0.7 percent). Smaller visibility improvements are predicted in the Southwest (0.3 percent).

Table VII-5. Summary of 2030 Visibility Degradation Estimates by Region: Residential (Annual Average Deciviews)

Study Regions	*2030 Base Case*	*Change*[a]	*Percent Change*
Southeast	23.79	-0.27	-1.1%
Southwest	17.49	-0.09	-0.5%
California	20.91	-0.04	-0.2%
Northeast	24.53	-0.12	-0.5%
North Central	22.52	-0.29	-1.3%
South Central	20.28	-0.24	-1.2%
Rocky Mountain	18.27	-0.16	-0.9%
Northwest	21.08	-0.28	-1.3%
National Average (unweighted)	22.00	-0.23	-1.0%

[a] The change is defined as the control case deciview level minus the base case deciview level.

Table VII-6. Summary of 2030 Visibility Degradation Estimates by Region: Recreational (Annual Average Deciviews)

Class I Visibility Regions	*2030 Base Case*	*Change*[a]	*Percent Change*
Southeast	22.78	-0.20	-0.9%
Southwest	17.61	-0.05	-0.3%
California	20.54	-0.04	-0.2%
Northeast/Midwest	21.34	-0.15	-0.7%
Rocky Mountain	17.80	-0.10	-0.6%
Northwest	22.09	-0.32	-1.4%
National Average (unweighted)	19.99	-0.12	-0.6%

[a] The change is defined as the control case deciview level minus the base case deciview level.

4. Nitrogen Deposition Estimates

This section presents the methods and results of estimating the potential reductions in airborne nitrogen deposition loadings to estuaries associated with the motor vehicle Tier 2 and fuel standards. A sampling of 12 estuaries (10 East Coast and 2 Gulf Coast estuaries) were used for this analysis because of the availability of necessary data and their potential representativeness. For each estuary, we completed the following steps as part of this analysis:

Baseline loadings of atmospherically supplied nitrogen were obtained from data provided in Valigura et al (1996) and from local offices of the Chesapeake Bay Program and the National Estuary Program,

- Deposition from atmospheric emissions were divided into local and regional areas that contribute to airborne nitrogen deposition,

- Deposition coefficients, which relate NOx emission changes from a source region to nitrogen deposition changes at a receptor region, were derived for local and regional contributors, and

- Changes in nitrogen deposition loadings were estimated by multiplying NOx emission changes for the local and regional contributing areas by the appropriate deposition coefficients.

For five of the 12 estuaries, estimates of both direct deposition to the tidal waters and indirect deposition to the entire watershed were available from the literature. For the remaining seven estuaries, only the direct deposition estimates were available. Therefore, to obtain indirect deposition estimates where missing, we used RADM-derived nitrogen flux for the watershed (Dennis, 1997). This analysis assumes that 10 percent of nitrogen deposited onto the watershed is delivered via export (pass-through) to the estuary.[13] This calculated indirect deposition value is then added to the direct deposition value obtained from the literature to arrive at the total load from atmospheric deposition.

As stated in Step 4 above, the nitrogen deposition results are heavily dependent upon the deposition coefficients that estimate the impact of NOx emission changes on nitrogen deposition loadings. For this analysis, two S-R coefficients, an *alpha* and a *beta*, were developed for each estuary. The alpha coefficient relates local emissions to deposition and the beta coefficient relates regional emissions to deposition. These coefficients are calculated for each estuary using

[13] This assumption is consistent with reported case studies such as Valiela et al, 1997. These authors report that 89% of atmospherically deposited nitrogen was retained by the watershed of Waquoit Bay, suggesting an 11% pass through factor.

deposition outputs from RADM as employed for the final Regional NOx SIP Call (EPA, 1998b). More detail on this approach and results may be found in Pechan-Avanti (1999).

Table VII-7 provides a summary of the baseline deposition and change in nitrogen deposition estimates for the selected estuaries as a result of the Tier 2 rule. As shown, implementation of the Tier 2 controls results in a 14.1 percent reduction in the average annual deposition across these estuaries. These predicted reductions range from a low of 10.1 percent for Delaware Inland Bay to a high of 15.5 percent for Long Island Sound.

Table VII-7. Summary of 2030 Nitrogen Deposition in Selected Estuaries and Changes Due to Tier 2 Standards (million kg/year)

Estuary	*2030 Base Case*	*Change[a]*	*Percent Change*
Albemarle/Pamlico Sound	13.20	-1.83	-13.8%
Cape Cod Bay	4.63	-0.65	-14.1%
Chesapeake Bay	20.71	-2.80	-13.5%
Delaware Bay	4.08	-0.57	-14.0%
Delaware Inland Bays	0.59	-0.06	-10.1%
Gardiners Bay	1.44	-0.21	-14.9%
Hudson River/Raritan Bay	4.59	-0.69	-15.1%
Long Island Sound	6.71	-1.04	-15.5%
Massachusetts Bay	1.58	-0.22	-14.2%
Narragansett Bay	1.37	-0.20	-14.3%
Sarasota Bay	0.46	-0.06	-14.1%
Tampa Bay	2.96	-0.44	-14.9%
All Selected Estuaries	62.32	-8.77	-14.1%

[a] Change is defined here as the emissions level after implementing the Tier 2 rule minus the base case emissions.

C. Benefit Analysis

1. Methods for Estimating Benefits from Air Quality Improvements

Environmental and health economists have a number of methods for estimating the economic value of improvements in (or deterioration of) environmental quality. The method used in any given situation depends on the nature of the effect and the kinds of data, time and resources that are available for investigation and analysis. This section provides an overview of the methods EPA selected to monetize the benefits included in the Tier 2/Gasoline Sulfur RIA.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure economic benefits for individual rulemakings. As a result, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary benefits research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors in order to improve the accuracy and robustness of benefits estimates.

In general, economists tend to view an individual's willingness-to-pay for a improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available and conservative measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate.

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or bike helmets). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between use values and non-use values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman, 1993), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit. Non-use values are most frequently divided into two categories: existence values and bequest values. Existence values refer to situations where individuals value (are willing to pay for) the knowledge of an improved environmental state (or avoidance of a deteriorating environmental state) . An example is the willingness to pay (WTP) for the preservation of the blue whale even when an individual has no plan to take a trip to observe the species nor to derive any direct benefit from its survival. Existence values commonly rise from philosophical, ethical, or religious attitudes about the rights of nature and the responsibilities of humans. The other commonly posited category of non-use benefits is bequest value. People are willing to devote resources to environmental preservation because of their perceived obligation or desire to leave higher states of environmental quality to future generations. Bequest values can also be thought of as arising from the philosophical, ethical, and religious beliefs of individuals.

Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by the final Tier 2/Gasoline Sulfur rule cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used. Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable estimate of true economic benefits when PM levels are reduced. A variation on the avoided cost method is used to provide an alternative estimate of the benefits of reductions in nitrogen deposition to estuaries (see Sections C.4 and F). Avoided costs methods are also used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see section D).

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the value of a statistical life for use in the estimate of benefits from mortality reductions. There exists no market where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk (see section D). For measurement of health benefits, this analysis captures the WTP for most use and non-use values, with the exception of the value of avoided hospital admissions, which only captures the avoided cost of illness.

The most direct way to measure the economic value of air quality changes is in cases where the endpoints have market prices. For the final rule, this can only be done for effects on commercial agriculture and forestry. Well-established economic modeling approaches are used to predict price changes that result from predicted changes in agricultural and forestry outputs. Consumer and producer surplus measures can then be developed to give reliable indications of the benefits of changes in ambient air quality for these categories (see section E).

Estimating benefits for visibility and ecosystem services is a more difficult and less precise exercise because the endpoints are not directly or indirectly valued in markets. For example, the loss of a species of animal or plant from a particular habitat does not have a well-defined price. The contingent valuation method (CVM) has been employed in the economics literature to value endpoint changes for both visibility and ecosystem functions (Chestnut and Dennis, 1997). CVM values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of CVM. EPA believes that well-designed and well-executed CVM studies are valid for estimating the benefits of air quality regulation[14].

2. Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty[15]. This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of concentration-response (C-R) functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and

[14]Concerns about the reliability of value estimates that come from CVM studies have dominated debates about the methodology, since research has shown that bias can be introduced easily into these studies, especially if they are not carefully done. Accurately measuring willingness to pay for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP; 2) whether the good to be valued is comprehended and accepted by the respondent; 3) whether the WTP elicitation format is designed to minimize strategic responses; 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income; 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods; and 6) the extent to which WTP responses are consistent with established economic principles.

[15] It should be recognized that in addition to uncertainty, the annual benefit estimates for the final Tier 2/Gasoline Sulfur rule presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as electricity demand and weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to much larger impacts on total benefits. A more thorough discussion of uncertainty can be found in the benefits technical support document (TSD) for this RIA, *Tier II Final Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results* (Abt Associates, 1999).

Some key sources of uncertainty in each stage of the benefits analysis are:

- gaps in scientific data and inquiry
- variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling
- errors in measurement and projection for variables such as population growth rates
- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions
- biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table VII-8. Given the wide variety of sources for uncertainty and the potentially large degree of uncertainty about any primary estimate, it is necessary for us to address this issue in several ways. These include qualitative discussions, probabilistic assessments, and alternative calculations. For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the information necessary to estimate an uncertainty distribution is not available. Even for individual endpoints, there is usually more than one source of uncertainty. This makes it difficult to provide a quantified uncertainty estimate. For example, the C-R function used to estimate avoided premature mortality has an associated standard error which represents the sampling error around the pollution coefficient in the estimated C-R function. It would be possible to report a confidence interval around the estimated incidences of avoided premature mortality based on this standard error. However, this would omit the contribution of air quality changes, baseline population incidences, projected populations exposed, and transferability of the C-R function to diverse locations to uncertainty about premature mortality. Thus, a confidence interval based on the standard error would provide a misleading picture about the overall uncertainty in the estimates. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the benefits TSD for this RIA (Abt Associates, 1999). But, this information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Our approach to characterizing model uncertainty in the estimate of total benefits is to present a primary estimate, based on the best available scientific literature and methods, and to then provide alternative calculations to illustrate the effects of uncertainty about key analytical assumptions. We do not attempt to assign probabilities to these alternative calculations, as we believe this would only add to the uncertainty of the analysis or present a false picture about the precision of the results[16]. Instead, the reader is invited to examine the impact of applying the

[16] Some recent benefit-cost analyses in Canada and Europe (Holland, et al., 1999; Lang, et al., 1995) have estimated ranges of benefits by assigning *ad hoc* probabilities to ranges of parameter values for different endpoints. Although this does generate a quantitative estimate of an uncertainty range, the estimated points on these distributions are themselves highly uncertain and very sensitive to the subjective judgements of the analyst. To avoid these subjective judgements, we choose to allow the reader to determine the weights they would assign to alternative estimates.

Table VII-8. Primary Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
-The value of the ozone- or PM-coefficient in each C-R function. -Application of a single C-R function to pollutant changes and populations in all locations. -Similarity of future year C-R relationships to current C-R relationships. -Correct functional form of each C-R relationship. -Extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study.
2. Uncertainties Associated With Ozone and PM Concentrations
-Estimating future-year baseline and hourly ozone and daily PM concentrations. -Estimating the change in ozone and PM resulting from the control policy.
3. Uncertainties Associated with PM Mortality Risk
-No scientific literature supporting a direct biological mechanism for observed epidemiological evidence. -Direct causal agents within the complex mixture of PM responsible for reported health effects have not been identified. -The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. -Possible confounding in the epidemiological studies of $PM_{2.5}$, effects with other factors (e.g., other air pollutants, weather, indoor/outdoor air, etc.). -The extent to which effects reported in the long-term studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. -Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects
-What portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion might occur in subsequent years.
5. Uncertainties Associated With Baseline Incidence Rates
-Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. -Current baseline incidence rates may not well approximate what baseline incidence rates will be in the year 2007. -Projected population and demographics -- used to derive incidences – may not well approximate future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
-Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. -Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors.
7. Uncertainties Associated With Aggregation of Monetized Benefits
-Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified benefit categories will cause total benefits to be underestimated.

different assumptions on the estimate of total benefits. While it is possible to combine all of the alternative calculations with a positive impact on benefits to form a “high” estimate or all of the alternative calculations with a negative impact on benefits to form a “low” estimate, this would not be appropriate because the probability of all of these alternative assumptions occurring simultaneously is extremely low. Instead, the alternative calculations are intended to demonstrate the sensitivity of our benefits results to key parameters which may be uncertain. Alternative calculations are presented in Table VII-18.

Many benefits categories, while known to exist, do not have enough information available to provide a quantified or monetized estimate. The uncertainty regarding these endpoints is such that we could determine neither a primary estimate nor a plausible range of values.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table VII-8). The total benefits estimate may understate or overstate actual benefits of the rule. The remainder of this section describes in greater detail two potential sources of uncertainty that can impact multiple aspects of the analysis: 1) the inability to quantify or monetize many of the benefits and costs associated with the rule; and 2) adjustments for changes in income in the future.

a. Unquantifiable Environmental Benefits and Costs

In considering the monetized benefits estimates, the reader should remain aware of the many limitations for conducting these analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the PM and ozone-induced adverse effects listed in Table VII-1. For many health and welfare effects, such as PM-related materials damage, reliable C-R functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefits categories, the benefits estimates presented in this analysis would increase. Unquantified benefits are qualitatively discussed in the health and welfare effects sections. In addition to unquantified benefits, there may also be environmental costs that we are unable to quantify. Several of these environmental cost categories are related to nitrogen deposition, while one category is related to the issue of ultraviolet light. These endpoints are qualitatively discussed in the health and welfare effects sections as well. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

b. Projected Population and Income Growth

As indicated above, our analysis predicts the benefits of the Tier 2/Gasoline Sulfur rule in 2030. As such, we use projections of populations in 2030. The total projected population in the 47 states covered by the Tier 2/Gasoline Sulfur rule in 2030 is 300 million. The total projected population potentially affected by air quality changes resulting from the Tier 2/Gasoline Sulfur rule includes California, which adds an additional 45 million people. These projections are uncertain, although they are based on projection methods used by the U.S. Census Bureau (Abt Associates, 1999b). To the extent that populations are over- or under-predicted, benefits may be over- or under-stated.

Our analysis does not attempt to adjust benefits estimates to reflect expected growth in real income. Economic theory argues, however, that WTP for most goods (such as environmental protection) will increase if real incomes increase. There is substantial empirical evidence that the income elasticity[17] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. While many analyses assume that the income elasticity of WTP is unit elastic (i.e., ten percent higher income level implies a ten percent higher willingness to pay to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one and thus inelastic. The effects of income changes on WTP estimates can influence benefit estimates in two different ways: (i) as changes that reflect estimates of income change in the affected population over time; and (ii) as changes based on differences in income between study populations and the affected populations at a particular time. Empirical evidence of the effect of income on WTP gathered to date is based on studies examining the latter. Income elasticity adjustments to better account for changes over time, therefore, will necessarily be based on potentially inappropriate data. The degree to which WTP may increase for the specific health and welfare benefits provided by the final Tier 2/Gasoline Sulfur rule is not estimated due to the high degree of uncertainty in the income elasticity information.

D. Assessment of Human Health Benefits

The most significant monetized benefits of reducing ambient concentrations of PM and ozone are attributable to reductions in health risks associated with air pollution. EPA's criteria documents for ozone and PM list numerous health effects known to be linked to ambient concentrations of these pollutants (EPA, 1996). This section describes individual effects and the methods used to quantify and monetize changes in the expected number of incidences of various health effects.

[17]Income elasticity is a common economic measure equal to the percentage change in WTP for a one percent change in income.

In section 1, we discuss how we have determined the baseline incidences for the health effects impacted by changes in PM and ozone. In section 2, we explain how we deal with the issue of health effects thresholds. In section 3, we describe how we quantify and value changes in individual health effects. Finally, in section 4 we present quantified estimates of the reductions in health effects resulting from the Tier 2 standards and their associated monetary values.

1. Estimating Baseline Incidences for Health Effects

The epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than an estimate of the absolute number of avoided cases. For example, a typical result might be that a ten $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by three percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases.

Because most PM and ozone studies that estimate C-R functions for mortality considered only non-accidental mortality, we adjusted county-specific baseline total mortality rates used in the estimation of PM-related premature mortality to provide a better estimate of county-specific non-accidental mortality. We multiplied each county-specific mortality rate by the ratio of national non-accidental mortality to national total mortality (0.93) (U.S. Centers for Disease Control, 1999a). An additional adjustment was necessary to provide baseline incidences for adults 30 and older for use in the Pope, et al. (1995) PM mortality C-R function. We estimated county-specific baseline mortality incidences for this population by applying national age-specific death rates to county-specific age distributions, and adjusting the resulting estimated age-specific incidences so that the estimated total incidences (including all ages) equals the actual county-specific total incidences.

County-level incidence rates are not available for other endpoints. We used national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level.

2. Accounting for Potential Health Effect Thresholds

When conducting clinical (chamber) and epidemiological studies, C-R functions may be estimated with or without explicit thresholds. Air pollution levels below the threshold are assumed to have no associated adverse health effects. When a threshold is not assumed, as is often the case in epidemiological studies, any exposure level is assumed to pose a non-zero risk of response to at least one segment of the population.

The possible existence of an effect threshold is a very important scientific question and issue for policy analyses such as the final Tier 2/Gasoline Sulfur RIA. In the benefits analysis for the Tier 2 Proposal RIA, the low-end estimate of benefits assumed a threshold in PM health effects at 15 $\mu g/m^3$. However, the most recent advice from EPA's Science Advisory Board is that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM-related health effects considered in this analysis (EPA-SAB-Council-ADV-99-012, 1999). Therefore, for our benefits analysis of the final Tier 2/Gasoline Sulfur rule, we assume there are no thresholds for modeling health effects. It is not appropriate to adopt a threshold for use in either the primary analysis or any alternative calculations because there is no adequate scientific evidence to support such a calculation. The potential impact of a health effects threshold on avoided incidences of PM-related premature mortality is explored as a key sensitivity analysis presented in Appendix VII-A.

3. Quantifying and Valuing Individual Health Endpoints

Health benefits of the final Tier 2/Gasoline Sulfur rule may be related to ozone only, PM only, or both pollutants. The ozone only health effects included in our primary benefits estimate are chronic asthma in adult males and decreased worker productivity. The PM only health effects include premature mortality, chronic bronchitis, acute bronchitis, upper and lower respiratory symptoms, shortness of breath, and work loss days[18]. The health effects related to both PM and ozone include hospital admissions, and minor restricted activity days.

For this analysis, we rely on C-R functions estimated in published epidemiological studies relating adverse health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table VII-9. A complete discussion of the C-R functions used for this analysis is contained in the benefits TSD for this RIA (Abt Associates, 1999).

[18] In the benefits analysis for the Tier 2 Proposal RIA, we also estimated reductions in the incidence of premature mortality associated with reduced exposures to ozone. At least some evidence has been found linking both PM and ozone with premature mortality. The SAB has raised concerns that mortality-related benefits of air pollution reductions may be overstated if separate pollutant-specific estimates, some of which may have been obtained from models excluding the other pollutants, are aggregated. In addition, there may be important interactions between pollutants and their effect on mortality (EPA-SAB-Council-ADV-99-012, 1999)

The Pope et al. (1995) study used to quantify PM-related mortality included only PM, so it is unclear to what extent it may include the impacts of ozone or other gaseous pollutants. Because of concern about overstating of benefits and because the evidence associating mortality with exposure to particulate matter is currently stronger than for ozone, only the benefits of PM-related premature mortality avoided are included in the total benefits estimate. The benefits associated with ozone reductions are presented as a sensitivity analysis in Appendix VII-A but are not included in the estimate of total benefits.

While a broad range of adverse health effects have been associated with exposure to elevated ozone and PM levels (as noted for example in Table VII-1 and described more fully in the ozone and PM criteria documents (EPA, 1996a, 1996b), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for three reasons: (i) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (ii) uncertainties in applying effect relationships based on clinical studies to the affected population; or (iii) a lack of an established C-R relationship.

When a single published study is selected as the basis of the C-R relationship between a pollutant and a given health effect, or "endpoint," applying the C-R function is straightforward. This is the case for most of the health endpoints selected for inclusion in the benefits analysis. A

Table VII-9. Endpoints and Studies Included in the Primary Analysis

Endpoint	*Pollutant*	*Study*	*Study Population*
Mortality			
Ages 30 and Older	PM	Pope et al. (1995)	Adults, 30 and older
Chronic Illness			
Chronic Bronchitis	PM	Multiple Studies	Multiple Studies
Chronic Asthma	Ozone	McDonnell et al. (1999)	Non-asthmatic adults, 27 and older
Hospital Admissions			
All Respiratory	PM, Ozone	Multiple Studies	Multiple Studies
Total Cardiovascular	PM, Ozone	Multiple Studies	Multiple Studies
Asthma-Related ER Visits	PM, Ozone	Multiple Studies	Multiple Studies
Other Illness			
Acute Bronchitis	PM	Dockery et al. (1996)	Children, 8-12
Upper Respiratory Symptoms	PM	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	PM	Schwartz et al. (1994)	Children, 7-14
Shortness of Breath	PM	Ostro et al. (1995)	African American asthmatic children, 7-12
Work Loss Days	PM	Ostro (1987)	Adults, 18-65
Minor Restricted Activity Days / Any of 19 respiratory Symptoms	PM, Ozone	Multiple Studies	Multiple Studies

single C-R function may be chosen over other potential functions because the underlying epidemiological study used superior methods, data or techniques, or because the C-R function is more generalized and comprehensive.

When several estimated C-R relationships between a pollutant and a given health endpoint have been selected, they are combined or pooled to derive a single estimate of the relationship. The benefits TSD provides details of the procedures used to combine multiple C-R functions (Abt Associates, 1999). Pooled C-R functions are used to estimate incidences of chronic bronchitis related to PM exposure, hospital admissions from cardiovascular and respiratory causes related to PM and ozone exposure, and emergency room visits for asthma related to PM and ozone exposure.

Whether the C-R relationship between a pollutant and a given health endpoint is estimated by a single function from a single study or by a pooled function of C-R functions from several studies, we apply that same C-R relationship at all locations in the U.S. Although the C-R relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available. While a single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates in other locations, these location-specific biases will to some extent cancel each other out when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on the general application of a single C-R function everywhere.

The appropriate economic value of a change in a health effect depends on whether the health effect is viewed ex ante (before the effect has occurred) or ex post (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore ex-ante WTP for changes in risk. However, epidemiological studies generally provide estimates of the expected number of incidences of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as an alternative estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of illness (COI) estimates generally understate the true value of avoiding a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect. Table VII-10 summaries the value estimates per health effect that we use in this analysis. Alternative values used to derive the alternative estimates listed in Table VII-18 are indicated in parentheses. Note that there is not a specific value listed for hospital admissions. This reflects the fact that there are a range of symptoms for which individuals are admitted, each of which has a different associated cost. The estimated benefit of avoided hospital admissions reflects the distribution of symptoms across the total incidence of hospital admissions. The study-specific values for hospital admissions can be found in the benefits TSD for this RIA (Abt Associates, 1999).

In the following sections, we describe individual health endpoints and the C-R functions we have selected to provide quantified estimates of the avoided health effects associated with the final Tier 2/Gasoline Sulfur rule. In addition, we discuss how these changes in health effects should be valued and indicate the value functions selected to provide monetized estimates of the value of changes in health effects.

Table VII-10. Unit Values Used for Economic Valuation of Health Endpoints

Health or Welfare Endpoint	*Estimated Value Per Incidence (1997$) Central Estimate*	*Derivation of Estimates*
Mortality	$5.9 million per statistical life	Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the section 812 Prospective analysis.
Chronic Bronchitis (CB)	$319,000	Value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Chronic Asthma	$31,000	Based on results reported in two studies (Blumenschein and Johannesson, 1998; O'Connor and Blomquist, 1997). Assumes a 5% discount rate and reflects adjustments for age distribution among adults (ages 27 and older) and projected life years remaining.
Hospital Admissions		
All Respiratory (ICD codes: 460-519)	variable — function of the analysis	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total respiratory illnesses) reported in Elixhauser (1993).
All Cardiovascular (ICD codes: 390-429)	variable — function of the analysis	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular illnesses) reported in Elixhauser (1993).
Emergency room visits for asthma	$280	COI estimate based on data reported by Smith et al. (1997).
Respiratory Ailments Not Requiring Hospitalization		
Upper Respiratory Symptoms (URS)	$23	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory. Symptoms (LRS)	$15	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.

Health or Welfare Endpoint	*Estimated Value Per Incidence (1997$) Central Estimate*	***Derivation of Estimates***
Acute Bronchitis	$55	Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994)
Shortness of Breath	$5.30	From Ostro, et al. 1995. This is the mean of the median estimates from two studies to avoid a day of shortness of breath, Dickie et al. 1991 (0.00) and Loehman et al., 1979 (13.00).
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	Variable	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1997$) (U.S. Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$47	Median WTP estimate to avoid 1 MRRAD – minor respiratory restricted activity day -- from Tolley et al.(1986) .

a. Premature Mortality: Quantification

Both acute and chronic exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. Because of the extreme nature of this endpoint and the high monetary value associated with risks to life, reductions in the risk of premature mortality are the most important health endpoint quantified in this analysis, accounting for over 90 percent of the total monetized benefits. However, considerable uncertainty exists, both among economists and policymakers, as to the appropriate way to value reductions in mortality risks. Because of these factors, we include a more detailed discussion for premature mortality than for other health effects.

Health researchers have consistently linked air pollution, especially PM, with increases in premature mortality. A substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. Much of this literature is summarized in the 1996 PM Criteria Document (U.S. EPA, 1996a). There is much about this relationship that is still uncertain, however, as stated in preamble to the 1997 PM National Ambient Air Quality Standards (U.S. EPA. 40 CFR 50, 1997), “the consistency of the results of the epidemiological studies from a large number of different locations and the coherent nature of the observed effects are suggestive of a likely causal role of ambient PM in contributing to the reported effects,” which include premature mortality. The National Academy of Sciences, in their report on research priorities for PM (National Academy of Sciences, 1998), indicate that “there is a great deal of uncertainty about the implications of the findings [of an association between PM and premature mortality] for risk management, due to the limited scientific information about the specific types of particles that might cause adverse health effects, the contributions of particles of outdoor origin to actual human exposures, the toxicological mechanisms by which the particles might cause adverse health effects, and other important questions.” EPA acknowledges these uncertainties, however, for this analysis, we assume a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the scientific literature (U.S. EPA, 1996a).

It is currently unknown whether there is a time lag (a delay between changes in PM exposures and changes in mortality rates) in the chronic PM/premature mortality relationship. The existence of such a lag is important for the valuation of premature mortality incidences because economic theory suggests that benefits occurring in the future should be discounted. Although there is no specific scientific evidence of the existence or structure of a PM effects lag, current scientific literature on adverse health effects, such as those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. This same smoking-related literature implies that lags of up to a few years are plausible. Adopting the lag structure used in a illustrative calculation for the Tier 2 Proposal RIA and endorsed by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), we assume a five-year lag structure, with 25 percent of premature deaths occurring in the first year, another 25 percent in the second year, and 16.7 percent in each of the remaining three years. To explore the uncertainty surrounding this lag structure, Appendix VII-A contains a sensitivity analysis showing how different lag structures affect the estimated value of reductions in premature mortality.

Two types of exposure studies (short-term and long-term) have been used to estimate a PM/premature mortality relationship. Short-term exposure studies attempt to relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term exposure studies examine the potential relationship between longer-term (e.g., annual) changes in exposure to PM and annual mortality rates. Researchers have found significant correlations using both types of studies (U.S. EPA, 1996a); however, for this analysis, following SAB advice (EPA-SAB-COUNCIL-ADV-99-005, 1999) we rely exclusively on long-term studies to quantify PM mortality effects.

Following guidance from the SAB (EPA-SAB-COUNCIL-ADV-99-005, 1999), we prefer studies to use long-term studies that employ a prospective cohort design over those that use an ecologic or population-level design. Prospective cohort studies follow individuals forward in time for a specified period, periodically evaluating each individual's exposure and health status. While the long-term study design is preferred, they are expensive to conduct and consequently there are relatively few well designed long-term studies. For PM, there have been only a few, and the SAB has explicitly recommended use of only one — the Pope, et al. (1995) prospective cohort study in estimating avoided premature mortality from reductions in ambient PM concentrations (EPA-SAB-COUNCIL-ADV-99-005, 1999). We follow this recommendation and are consistent with the modeling of mortality effects of PM in both the Section 812 Retrospective and Prospective Reports to Congress. The Pope et al. study is recommended in preference to other available long-term studies because it uses better statistical methods, has a much larger sample size, the longest exposure interval, and more locations (51 cities) in the United States than other studies.

Although we use the Pope study exclusively to derive our primary estimates of avoided premature mortality, the C-R function based on Dockery et al. (1993) may provide a reasonable alternative estimate (EPA-SAB-COUNCIL-ADV-99-012, 1999). While the Dockery et al. study used a smaller sample of individuals from fewer cities than the study by Pope et al., it features improved exposure estimates, a slightly broader study population (adults aged 25 and older), and a follow-up period nearly twice as long as that of Pope et al. The Dockery et al. (1993) study finds a larger effect of PM on premature mortality. We present an alternative estimate of premature adult mortality associated with long-term PM exposure based on Dockery et al. (1993) in Table VII-18. We emphasize, however, that based on SAB advice, the Pope et al. (1995) derived estimate is our primary estimate of the effect of the final Tier 2/Gasoline Sulfur rule on this important health effect**.**

b. Premature Mortality: Valuation

We estimate the monetary benefit of reducing premature mortality risk using the “value of statistical lives saved” (VSL) approach, even though the actual valuation is of small changes in mortality risk experienced by a large number of people. The VSL approach applies information from several value-of-life studies to determine a reasonable benefit of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be $5.9 million in 1997 dollars. This represents an intermediate value from a variety of estimates that appear in the economics literature, and is a value EPA has frequently used in RIAs for other rules and in the Section 812 reports to Congress. This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the Section 812 reports as “applicable to policy analysis.” The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria as Viscusi in his review of value-of-life studies. The $5.9 million estimate is consistent with Viscusi’s conclusion (updated to 1997$) that “most of the reasonable estimates of the value of life are clustered in the $3.7 to $8.6 million range.” Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. The 26 studies used to form the distribution of the value of a statistical life are listed in Table VII-11. As indicated in the previous section on quantification of premature mortality benefits, we assume for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the five years following exposure. To take this into account in the valuation of reductions in premature mortality, we apply an annual five percent discount rate to the value of premature mortality occurring in future years.

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. Some of the alternative approaches that have been proposed for valuing reductions in mortality risk are discussed in Text Box 1. There is general agreement that the value to an individual of a reduction in mortality risk can vary based on several factors, including the age of the individual, the type of risk, the level of control the individual has over the risk, the level of risk aversion, and the health status of the individual. While the empirical basis for adjusting the $5.9 million VSL for many of these factors does not yet exist, a thorough discussion of these factors is contained in the benefits TSD for this RIA (Abt Associates, 1999). EPA recognizes the need for investigation by the scientific community to develop additional empirical support for adjustments to VSL for the factors mentioned above.

Table VII-11. Summary of Mortality Valuation Estimates[a]

Study	*Type of Estimate*	*Valuation per Statistical Life (millions of 1997 $)*
Kneisner and Leeth (1991) (US)	Labor Market	0.7
Smith and Gilbert (1984)	Labor Market	0.9
Dillingham (1985)	Labor Market	1.1
Butler (1983)	Labor Market	1.4
Miller and Guria (1991)	Contingent Valuation	1.5
Moore and Viscusi (1988)	Labor Market	3.1
Viscusi et al. (1991)	Contingent Valuation	3.3
Gegax et al. (1985)	Contingent Valuation	4.1
Marin and Psacharopoulos (1982)	Labor Market	3.4
Kneisner and Leeth (1991) (Australia)	Labor Market	4.1
Gerking et al. (1988)	Contingent Valuation	4.2
Cousineau et al. (1988)	Labor Market	4.4
Jones-Lee (1989)	Contingent Valuation	4.7
Dillingham (1985)	Labor Market	4.8
Viscusi (1978; 1979)	Labor Market	5.0
R.S. Smith (1976)	Labor Market	5.6
V.K. Smith (1983)	Labor Market	5.8
Olson (1981)	Labor Market	6.4
Viscusi (1981)	Labor Market	8.0
R.S. Smith (1974)	Labor Market	8.8
Moore and Viscusi (1988)	Labor Market	9.0
Kneisner and Leeth (1991) (Japan)	Labor Market	9.3
Herzog and Schlottman (1987)	Labor Market	11.2
Leigh and Folson (1984)	Labor Market	11.9
Leigh (1987)	Labor Market	12.8
Garen (1988)	Labor Market	16.6

[a] Based on Viscusi (1992). The values in Viscusi have been updated to 1997 $, as detailed in (Abt Associates, 1999).

Text Box 1
Alternative Approaches for Assessing the Value of Reduced Mortality Risk

Stated preference studies – These studies use survey responses to estimate WTP to avoid risks. *Strengths:* flexible approach allowing for appropriate risk context, good data on WTP for individuals. *Weaknesses:* Risk information may not be well-understood by respondents and questions may be unfamiliar.

Consumer market studies – These studies use consumer purchases and risk data (e.g. smoke detectors) to estimate WTP to avoid risks. *Strengths:* uses revealed preferences and is a flexible approach. *Weaknesses:* very difficult to estimate both risk and purchase variables.

Value of statistical life year – Provides an annual equivalent to value of statistical life estimates. *Strengths:* provides financially accurate adjustment for age at death. *Weaknesses:* adjustment may not reflect how individuals consider life-years; assumes equal value for all remaining life-years.

Quality adjusted life year – Applies quality of life adjustment to life-extension data, uses cost-effectiveness data to value. *Strengths:* widely used in public health literature to assess private medical interventions. *Weaknesses:* lack of data on health state indices and life quality adjustments that are applicable to an air pollution context.

WTP for a change in survival curve – Reflects WTP for change in risk, potentially incorporates age-specific nature of risk reduction. *Strengths:* theoretically preferred approach that most accurately reflects risk reductions from air pollution control. *Weaknesses:* almost no empirical literature available; difficulty in obtaining reliable values.

WTP for a change in longevity – Uses stated preference approach to generate WTP for longevity or longer life expectancy. *Strengths:* life expectancy is a familiar term to most individuals. *Weaknesses:* does not incorporate age-specific risk information; problems in adapting to air pollution context.

Cost-effectiveness – Determines the implicit cost of saving a life or life-year. *Strengths:* widely used in public health contexts. *Weaknesses:* health context is for private goods, dollar values do not necessarily reflect individual preferences.

One important factor in Text Box 1 for which the impact on total benefits can be illustrated is the difference in age distribution between the population affected by air pollution and the population for which most of the VSL estimates were developed. To address this factor we use the “value of statistical life-years lost” (VSLY) approach, recommended by the SAB as an appropriate alternative to the VSL approach (EPA-SAB-COUNCIL-ADV-98-003, 1998). To employ the value of statistical life-year (VSLY) approach, we first estimated the age distribution of those lives projected to be saved by reducing air pollution. Based on life expectancy tables, we calculate the life-years saved from each statistical life saved within each age and gender cohort. To value these statistical life-years, we hypothesized a conceptual model which depicted the relationship between the value of life and the value of life-years. The average number of life-years saved across all age groups for which data were available is 14 for PM-related mortality. The average for PM, in particular, differs from the 35-year expected remaining lifespan derived from existing wage-risk studies. Using the same distribution of value of life estimates used above, we estimated a distribution for the value of a life-year and combined it with the total number of estimated life-years lost. The details of these calculations are presented in the TSD for this RIA (Abt Associates, 1999).

c. Chronic Bronchitis: Quantification

Chronic bronchitis is characterized by mucus in the lungs and a persistent wet cough for at least three months a year for several years in a row. Chronic bronchitis affects an estimated five percent of the U.S. population (American Lung Association, 1999). There are a limited number of studies that have estimated the impact of air pollution on chronic bronchitis. Schwartz (1993) and Abbey et al.(1993; 1995) provide the evidence that long-term PM exposure gives rise to the development of chronic bronchitis in the U.S. Following the Section 812 Prospective Report (U.S. EPA, 1999a), our analysis pools the estimates from these studies to develop a C-R function linking PM to chronic bronchitis.

It should be noted that Schwartz used data on the *prevalence* of chronic bronchitis, not its *incidence*. Following the §812 Prospective Report, we assume that it is appropriate to estimate the percentage change in the prevalence rate for chronic bronchitis using the estimated coefficient from Schwartz's study in a C-R function, and then to assume this percentage change applies to a baseline incidence rate obtained from another source. For example, if the prevalence declines by 25 percent with a drop in PM, then baseline incidence drops by 25 percent with the same drop in PM..

d. Chronic Bronchitis: Valuation

The best available estimate of WTP to avoid a case of chronic bronchitis (CB) comes from Viscusi et al. (1991)[19]. The Viscusi et al. study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting an adjustment of the Viscusi et al. (1991) estimate of the WTP to avoid a sever case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (1992) study. Details of this adjustment procedure are provided in the benefits TSD for this RIA (Abt Associates, 1999).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: (1) the WTP to avoid a case of severe CB, as described by Viscusi et al.; (2) the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi et al.; and (3) the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean or average) of this distribution, which is about $320,000 (1997$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB. We describe the three underlying distributions, and the generation of the resulting distribution of WTP, in the benefits TSD for this RIA (Abt Associates, 1999).

e. Chronic Asthma: Quantification

Chronic asthma is characterized by repeated incidences of inflammation of the lungs. This causes restriction in the airways and results in shortness of breath, wheezing, and coughing. Asthma is also characterized by airway hyper responsiveness to stimuli. Chronic asthma affects over seven percent of the U.S. population (U.S. Centers for Disease Control, 1999b). Most studies have not identified an association between air quality and asthma. However, a recent study by McDonnell et al. (1999) provides a statistical association between ozone and the development of asthma in adult white, non-Hispanic males. Following the advice of the EPA

[19]The Viscusi et al. (1991) study was an experimental study intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the EPA Science Advisory Board (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity adjusted values from this study provide reasonable estimates of the WTP for chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values.

Science Advisory Board (EPA-SAB-COUNCIL-ADV-00-001, 1999) and the Section 812 Prospective Report, we have added this significant health effect to our benefit analysis since the proposal RIA. However, it should be noted that it is not clear that the intermittent, short-term, and relatively small changes in annual average ozone concentrations resulting from this rule are likely to measurably change long-term risks of asthma. The McDonnell et al. study is a prospective cohort analysis, measuring the association between long-term exposure to ambient concentrations of ozone and development of chronic asthma in adults. The study found a statistically significant effect for adult males, but none for adult females.

Some commentors have raised questions about the statistical validity of the associations found in this study and the appropriateness of transferring the estimated C-R function from the study populations (white, non-Hispanic males) to other male populations (i.e. African-American males). Some of these concerns include 1) no significant association was observed for female study participants also exposed to ozone; 2) the estimated C-R function is based on a cross-sectional comparison of ozone levels, rather than incorporating information on ozone levels over time; 3) information on the accuracy of self-reported incidence of chronic asthma was collected but not used in estimating the C-R function; 4) the study may not be representative of the general population because it included only those individuals living 10 years or longer within 5 miles of their residence at the time of the study; and 5) the study had a significant number of study participants drop out, either through death, loss of contact, or failure to provide complete or consistent information.

EPA believes that while these issues may result in increased uncertainty about this effect, none can be identified with a specific directional bias in the estimates. In addition, the study has been reviewed by the SAB and has been specifically recommended for inclusion in benefits analyses of changes in ozone concentrations (EPA-SAB-COUNCIL-ADV-00-001, 1999). EPA also believes it to be appropriate to apply the C-R function to all adult males over age 27 because no evidence exists to suggest that non-white adult males have a lower responsiveness to air-pollution. For other health effects such as shortness of breath, where the study population was limited to a specific group potentially more sensitive to air pollution than the general population (Ostro, et al., 1995), EPA has applied the C-R function only to the limited population. EPA recognizes the need for further investigation by the scientific community to confirm the statistical association identified in the McDonnell et al. study.

f. Chronic Asthma: Valuation

Similar to the valuation of chronic bronchitis, WTP to avoid chronic asthma is presented as the net present value of what would potentially be a stream of costs and lower well-being incurred over a lifetime. Estimates of WTP to avoid asthma are provided in two studies, one by Blumenschein and Johannesson (1998) and one by O'Conor and Blomquist (1997). Both studies use the contingent valuation method to solicit annual WTP estimates from individuals who have been diagnosed as asthmatics. The central estimate of lifetime WTP to avoid a case of chronic asthma among adult males, approximately $31,000, is the average of the present discounted value from the two studies. Details of the derivation of this central estimate from the two studies is provided in the benefits TSD for this RIA (Abt Associates, 1999).

g. Hospital Admissions: Quantification

There is a wealth of epidemiological information on the relationship between air pollution and hospital admissions for various respiratory and cardiovascular diseases; in addition, some studies have examined the relationship between air pollution and emergency room (ER) visits. Because most emergency room visits do not result in an admission to the hospital (the majority of people going to the ER are treated and return home) we treat hospital admissions and ER visits separately, taking account of the fraction of ER visits that do get admitted to the hospital.

Hospital admissions require the patient to be examined by a physician, and on average may represent more serious incidents than ER visits. The two main groups of hospital admissions estimated in this analysis are respiratory admissions and cardiovascular admissions. There is not much evidence linking ozone or PM with other types of hospital admissions. The only type of ER visits that have been linked to ozone and PM in the U.S. or Canada are asthma-related visits. To estimate the number of hospital admissions for respiratory illness, cardiovascular illness, and asthma ER visits, we pool the incidence estimates from a variety of U.S. and Canadian studies, using a random effects weighting procedure[20]. Details of the pooling procedure and a complete listing of the hospital admission studies used in our estimates can be found in the benefits TSD for this RIA (Abt Associates, 1999).

h. Hospital Admissions: Valuation

An individual's WTP to avoid a hospital admission will include, at a minimum, the amount of money he or she pays for medical expenses (i.e., payment towards the hospital charge and the associated physician charge) and the loss in earnings. In addition, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself.

[20]Because we are estimating ER visits as well as hospital admissions for asthma, we must avoid counting twice the ER visits for asthma that are subsequently admitted to the hospital. To avoid double-counting, the baseline incidence rate for emergency room visits is adjusted by subtracting the percentage of patients that are admitted into the hospital. The reported incidence rates suggest that ER visits for asthma occur 2.7 times as frequently as hospital admissions for asthma. The baseline incidence of asthma ER visits is therefore taken to be 2.7 times the baseline incidence of hospital admissions for asthma. To avoid double-counting, however, only 63% of the resulting change in asthma ER visits associated with a given change in pollutant concentrations is counted in the ER visit incidence change.

Even if they incurred no medical expenses and no loss in earnings, most individuals would still be willing to pay something to avoid the illness.

In the absence of estimates of WTP to avoid hospital admissions for specific illnesses, estimates of total cost-of-illness (COI) are typically used as conservative estimates. These estimates are biased downward because they do not include the value of avoiding the illness itself. Some analyses adjust COI estimates upward by multiplying by an estimate of the ratio of WTP to COI, to better approximate total WTP. Other analyses have avoided making this adjustment because of the possibility of over adjusting -- that is, possibly replacing a known downward bias with an upward bias. Consistent with the guidance offered by the EPA Science Advisory Board, the COI values used in this benefits analysis will not be adjusted to better reflect the total WTP (EPA-SAB-COUNCIL-ADV-98-003, 1998).

For the valuation of avoided hospital admissions, the current literature provides well-developed and detailed cost estimates of hospitalization by health effect or illness. Using illness-specific estimates of avoided medical costs and avoided costs of lost work-time that Elixhauser (1993) developed, we construct COI estimates specific to the suite of health effects defined by each C-R function. For example, we use twelve distinct C-R functions to quantify the expected change in respiratory admissions. Consequently in this analysis, we develop twelve separate COI estimates, each reflecting the unique composition of health effects considered in the individual studies. Details of the derivation of the values of avoided hospital admissions for respiratory and cardiovascular illnesses and asthma-related ER visits are provided in the benefits TSD for this RIA (Abt Associates, 1999).

i. Other Health Effects: Quantification

As indicated in Table VII-1, in addition to mortality, chronic illness, and hospital admissions, there are a number of acute health effects not requiring hospitalization that are associated with exposure to ambient levels of ozone and PM. The sources for the C-R functions used to quantify these effects are described below. A more complete description of these estimates is provided in the benefits TSD for this RIA (Abt Associates, 1999).

Around five percent of U.S. children between ages five and seventeen experience episodes of acute bronchitis annually (Adams, et al., 1995). Acute bronchitis is characterized by coughing, chest discomfort, and extreme tiredness. Incidences of acute bronchitis in children between the ages of five and seventeen are estimated using a C-R function developed from Dockery et al. (1996).

Incidences of lower respiratory symptoms (i.e., wheezing, deep cough) in children aged seven to fourteen are estimated using a C-R function developed from Schwartz et al. (1994). Because asthmatics have greater sensitivity to stimuli (including air pollution), children with asthma can be more susceptible to a variety of upper respiratory symptoms (i.e., runny or stuffy nose; wet cough; and burning, aching, or red eyes). Incidences of upper respiratory symptoms in asthmatic children aged nine to eleven are estimated using a C-R function developed from Pope et al. (1991).

Health effects from air pollution can also result in missed days of work (either from personal symptoms or from caring for a sick family member). Work loss days are estimated using a C-R function developed from Ostro (1987).

The endpoint minor restricted activity days (MRAD), which is also represented by the occurrence of any of 19 acute respiratory symptoms as defined by Krupnick et al. (1990), is a pooled estimate using estimates of C-R functions derived from Ostro and Rothschild (1989) and Krupnick et al. (1990).

As noted above, asthma affects over seven percent of the U.S. population. Air pollution is sometimes linked to development of asthma and occurrences of asthma symptoms (McDonnell, et al, 1999; Ostro, et al., 1991; Whittemore and Korn, 1980). Incidences of shortness of breath (in African American asthmatics[21]) are estimated using a C-R function derived from Ostro, et al. (1995). Other asthma related symptoms are included in the incidences of MRAD and any of 19 acute respiratory symptoms. Inclusion of separate estimates for these endpoints would result in double-counting of these benefits. Supplemental calculations for separate asthma only endpoints are included in Appendix VII-A.

In addition to the health effects discussed above, human exposure to PM and ozone is believed to be linked to health effects such as ozone-related premature mortality (Ito and Thurston, 1996; Samet, et al. 1997), PM-related infant mortality (Woodruff, et al., 1997), cancer (U.S. EPA, 1996b), increased emergency room visits for non-asthma respiratory causes (U.S. EPA, 1996a; 1996b), impaired airway responsiveness (U.S. EPA, 1996a), increased susceptibility to respiratory infection (U.S. EPA, 1996a), acute inflammation and respiratory cell damage (U.S. EPA, 1996a), premature aging of the lungs and chronic respiratory damage (U.S. EPA, 1996a; 1996b). An improvement in ambient PM and ozone air quality may reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are believed to be PM or ozone-induced, C-R data is not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects lends a downward bias to the monetized benefits presented in this analysis.

Another category of potential effects that may change in response to ozone strategies

[21]Shortness of breath due to PM exposure is not necessarily limited to African-American asthmatics. However, the Ostro, et al. study was based on a sample of African-American children, who may be more sensitive to air pollution than the general population so we chose not to extrapolate the findings to the general population.

results from the shielding provided by ozone against the harmful effects of ultraviolet radiation (UV-B) derived from the sun. The great majority of this shielding results from naturally occurring ozone in the stratosphere, but the 10% of total "column"ozone present in the troposphere also contributes (NAS, 1991). A variable portion of this tropospheric fraction of UV-B shielding is derived from ground level or "smog" ozone related to anthropogenic air pollution. Therefore, strategies that reduce ground level ozone will, in some small measure, increase exposure to UV-B from the sun.

While it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Smog ozone strategies, such as mobile source controls, are focused on decreasing peak ground level ozone concentrations, and it is reasonable to conclude that they produce a far more complex and heterogeneous spatial and temporal pattern of ozone concentration and UV-B exposure changes than do stratospheric ozone protection programs. In addition, the changes in long-term total column ozone concentrations are far smaller from ground-level programs. To properly estimate the change in exposure and impacts, it would be necessary to match the spatial and temporal distribution of the changes in ground-level ozone to the spatial and temporal distribution of exposure to ground level ozone and sunlight. More importantly, it is long-term exposure to UV-B that is associated with effects. Intermittent, short-term, and relatively small changes in ground-level ozone and UV-B are not likely to measurably change long-term risks of these adverse effects.

For all of these reasons, we were unable to provide reliable estimates of the changes in UV-B shielding associated with ground-level ozone changes. This inability lends an upward bias to the net monetized benefits presented in this analysis. It is likely that the adverse health effects associated with increases in UV-b exposure from decreased tropospheric ozone will, however, be relatively small because 1) the expected long-term ozone change resulting from this rule is small relative to total anthropogenic tropospheric ozone, which in turn is small in comparison to total column natural stratospheric and tropospheric ozone; 2) air quality management strategies are focused on decreasing peak ozone concentrations and thus may change exposures over limited areas for limited times, 3) people often receive peak exposures to UV-B in coastal areas where sea or lake breezes reduce ground level pollution concentrations regardless of strategy, and 4) ozone concentration changes are greatest in urban areas and areas immediately downwind of urban areas. In these areas, people are more likely to spend most of their time indoors or in the shade of buildings, trees or vehicles.

j. Other Health Effects: Valuation

The valuation of a specific short-term morbidity endpoint is generally estimated by representing the illness as a cluster of acute symptoms. For each symptom, the WTP is calculated. These values, in turn, are aggregated to arrive at the WTP to avoid a specific short term condition. For example, the endpoint lower respiratory symptoms (LRS) is represented by two or more of the following symptoms: runny or stuffy nose; coughing; and eye irritation. The WTP to avoid one day of LRS is the sum of values associated with these symptoms. The primary advantage of this approach is that is provides some flexibility in constructing estimates to represent a variety of health effects.

Valuation estimates for individual minor health effects are listed in Table 11-10. Derivation of the individual valuation estimates is provided in the benefits TSD for this RIA. Mean estimates range from $5.30 for an avoided incidence of shortness of breath to $45 for an avoided incidence of acute bronchitis. The value of work loss days varies depending on the location of an affected population. Using the median daily wage, the value of a work loss day is $83.

k. Lost Worker Productivity: Quantification and Valuation

While not technically a health effect, lost worker productivity related to pollution exposure is presumably linked to reductions in the physical capabilities of workers in outdoor jobs. The value of lost worker productivity due to ozone exposure is directly estimated based on a study of California citrus workers (Crocker and Horst, 1981 and U.S. EPA, 1994). The study measured productivity impacts as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration (or the percentage change in income for a one percent change in ambient ozone concentration). The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income.

l. Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

Applying the C-R and valuation functions described above to the estimated changes in ozone and PM yields estimates of the number of avoided incidences (i.e. premature mortalities, cases, admissions, etc.) and the associated monetary values for those avoided incidences. These estimates are presented in Table VII-12. All of the monetary benefits are in constant 1997 dollars.

Not all known PM and ozone related health effects could be quantified or monetized. These unmonetized benefits are indicated by place holders, labeled B_1 and B_2. Unquantified physical effects are indicated by U_1 and U_2. The estimate of total monetized health benefits is thus equal to the subset of monetized PM and ozone related health benefits plus $\mathbf{B_H}$, the sum of the unmonetized health benefits.

The largest monetized health benefit is associated with reductions in the risk of premature mortality. The next largest benefit is for chronic bronchitis reductions, although this value is more than an order of magnitude lower than for premature mortality. Minor restricted activity days, work loss days, and worker productivity account for the majority of the remaining benefits. The remaining categories account for less than $10 million each, however, they represent a large number of avoided incidences affecting many individuals.

Alternative calculations for premature mortality incidences and valuation are presented in Table VII-18. An alternative calculation is also provided in that table for chronic bronchitis incidences.

Table VII-12. Estimated Annual Health Benefits Associated With Air Quality Changes Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	Avoided Incidence[c] (cases/year)	Monetary Benefits[d] (millions 1997$)
PM-related Endpoints[a]		
Premature mortality[b] (adults, 30 and over)	4,300	$23,380
Chronic bronchitis	2,300	$730
Hospital Admissions from Respiratory Causes	1,200	$10
Hospital Admissions from Cardiovascular Causes	500	$10
Emergency Room Visits for Asthma	900	$<1
Acute bronchitis (children, 8-12)	7,900	$<1
Lower respiratory symptoms (LRS) (children, 7-14)	87,100	$<5
Upper respiratory symptoms (URS) (asthmatic children, 9-11)	86,500	$<5
Shortness of breath (African American asthmatics, 7-12)	17,400	$<1
Work loss days (WLD) (adults, 18-65)	682,900	$70
Minor restricted activity days (MRAD)/Acute respiratory symptoms	3,628,500	$170
Other PM-related health effects[e]	U_1	B_1
Ozone-related Endpoints		
Chronic asthma (adult males, 27 and over)	400	$10
Hospital Admissions from Respiratory Causes	1,000	$10
Hospital Admissions from Cardiovascular Causes	300	$<5
Emergency Room Visits for Asthma	400	$<1
Minor restricted activity days (MRAD)/Acute respiratory symptoms	2,226,500	$100
Decreased worker productivity (adult working population)	—	$140
Other ozone-related health effects[e]	U_2	B_2
CO-related health effects[e]	U_3	B_3
HAPS-related health effects[e]	U_4	B_4
Monetized Total Health-related Benefits[f]	—	$24,630+$\mathbf{B_H}$

[a] PM reductions are due to reductions in NOx and SO_2 resulting from the Tier 2/Gasoline Sulfur rule.
[b] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the estimated value assumes the 5 year distributed lag structure described earlier.
[c] Incidences are rounded to the nearest 100. [d] Dollar values are rounded to the nearest 10 million.
[e] A detailed listing of unquantified PM, ozone, CO, and HAPS related heatlh effects is provided in Table VII-1.
[f] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_1+B_2

E. Assessment of Human Welfare Benefits

Particulate matter and ozone have numerous documented effects on environmental quality that affect human welfare. These welfare effects include direct damages to property, either through impacts on material structures or by soiling of surfaces, direct economic damages in the form of lost productivity of crops and trees, indirect damages through alteration of ecosystem functions, and indirect economic damages through the loss in value of recreational experiences or the existence value of important resources. EPA's criteria documents for ozone and PM list numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (U.S. EPA, 1996a, 1996b). This section describes individual effects and how we quantify and monetize them. These effects include changes in crop yields, visibility, and nitrogen deposition to estuaries.

In section 1, we describe how we quantify and value changes in visibility, both in federal Class I areas (national parks and wilderness areas) and in the areas where people live and work. In section 2, we describe how we value the benefits of increased agricultural and commercial forest yields resulting from decreased levels of ambient ozone. In section 3, we describe the damage to materials caused by particulate matter. In section 4, we discuss the effects of nitrogen deposition on ecosystems (especially estuarine ecosystems) and describe how we quantify changes in nitrogen loadings. Finally, in section 6, we summarize the monetized estimates for welfare effects.

1. Visibility Benefits

Changes in the level of ambient particulate matter caused by the final Tier 2/Gasoline Sulfur rule will change the level of visibility in much of the U.S. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Grand Canyon. This section discusses the measurement of the economic benefits of visibility.

It is difficult to quantitatively define a visibility endpoint that can be used for valuation. Increases in PM concentrations cause increases in light extinction. Light extinction is a measure of how much the components of the atmosphere absorb light. More light absorption means that the clarity of visual images and visual range is reduced, *ceteris paribus.* Light absorption is a variable that can be accurately measured. Sisler (1996) created a unitless measure of visibility based directly on the degree of measured light absorption called the *deciview*. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10 percent in available light. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." Air quality models were used to predict the change in visibility, measured in deciviews, of the areas affected by the final Tier 2/Gasoline Sulfur rule[22].

EPA considers benefits from two categories of visibility changes: residential visibility and recreational visibility. In both cases economic benefits are believed to consist of both use values and non-use values. The use values include the aesthetic benefits of better visibility, improved road and air safety, and enhanced recreation in activities like hunting and birdwatching. The non-use values are based on people's beliefs that the environment ought to exist free of human-induced haze. Non-use values may be a more important component of value for recreational areas, particularly national parks and monuments.

Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas, and also in recreational areas **not** listed as federal Class I areas[23]. Recreational visibility improvements are those that occur specifically in federal Class I areas. A key distinction is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the U.S. are assumed to derive some benefit from improvements in Class I areas. Values are assumed to be higher if the Class I area is located close to their home.[24]

The results of air quality modeling of the Tier 2/Gasoline Sulfur rule show consistent improvements in visibility in all areas of the country. The mean improvement across all U.S. counties was 0.24 deciviews. The biggest improvements in visibility were most often found in heavily populated urban areas. Of the central counties of metropolitan areas with more than one million in population in 1993, 21 percent show an improvement of 0.5 deciviews or more. For suburban counties of these same regions, 11 percent are predicted to have visibility improvements of 0.5 deciview or more. For the 21 percent of metropolitan areas showing an improvement of 0.5 deciviews or more, the baseline visibility is 25.3. For the 11 percent of suburban counties in these regions, the baseline visibility is 23.3. And, baseline visibility in the 10 percent of counties with the largest improvements in visibility (baseline = 24.4 deciviews) is much worse than baseline visibility in those counties with no change in visibility (baseline = 18.1 deciviews). This suggests that the Tier 2/Gasoline Sulfur rule has the potential to provide large improvements in visibility in those areas with the worst baseline visibility conditions.

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[22]A change of less than 10 percent in the light extinction budget represents a measurable improvement in visibility, but may not be perceptible to the eye in many cases. Some of the average regional changes in visibility are less than one deciview (i.e. less than 10 percent of the light extinction budget), and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility which when considered together amount to perceptible changes in visibility.

[23] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

[24] For details of the visibility estimates discussed in this chapter, please refer to the benefits technical support document for this RIA (Abt Associates).

Only two existing studies provide defensible monetary estimates of the value of visibility changes. One is a study on residential visibility conducted in 1990 (McClelland, et. al., 1993) and the other is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990a, 1990b). Both utilize the contingent valuation method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CVM surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CVM study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas[25]. This study serves as an essential input to our estimates of the benefits of recreational visibility improvements in the primary benefits estimates. Based on SAB advice (EPA-SAB-COUNCIL-ADV-00-002, 1999), EPA has designated the McClelland et al. study as significantly less reliable for regulatory benefit-cost analysis, but it does provide useful estimates on the order of magnitude of residential visibility benefits. Residential visibility benefits are therefore only included as an alternative calculation in Table VII-18. The methodology for this alternative calculation, explained below, is similar to the procedure for recreational benefits.

The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. Respondents in five states were asked about their willingness to pay to protect national parks or NPS-managed wilderness areas within a particular region. The survey used photographs reflecting different visibility levels in the specified recreational areas. The visibility levels in these photographs were later converted to deciviews for the current analysis. The survey data collected were used to estimate a willingness-to-pay equation for improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. However, these values are not as defensible and are thus presented only as an alternative calculation in Table VII-18. A complete description of the benefits transfer method used to infer values for visibility changes in Class I areas outside the study regions is provided in the benefits TSD for this RIA (Abt Associates, 1999).

The estimated relationship from the Chestnut and Rowe study is only directly applicable

[25]An SAB advisory letter (EPA-SAB-COUNCIL-ADV-00-002, 1999) indicates that "many members of the Council believe that the Chestnut and Rowe study is the best available," however, the council did not formally approve use of these estimates because of concerns about the peer-reviewed status of the study. EPA believes the study has received adequate review and has been cited in numerous peer-reviewed publications (Chestnut and Dennis, 1997).

to the populations represented by survey respondents. EPA used benefits transfer methodology to extrapolate these results to the population affected by the final Tier 2/Gasoline Sulfur rule. A general willingness to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the final Tier 2/Gasoline Sulfur rule. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (1999). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut 1997). The benefits estimates here incorporate Chestnut's estimate that a one percent increase in income is associated with a 0.9 percent increase in WTP for a given change in visibility.

Using the methodology outlined above, EPA estimates that the total willingness to pay for the visibility improvements in Class I areas brought about by the final Tier 2/Gasoline Sulfur rule is $371 million. This value includes the value to households living in the same state as the Class I area as well as values for all households in the U.S. living outside the state containing the Class I area. A complete presentation of this method can be found in the benefits TSD for this RIA (Abt Associates, 1999).

For the alternative calculation for residential visibility, the McClelland study's results were used to calculate the parameter for the effect of deciview changes on WTP. The WTP equation was then run for the population affected by the final Tier 2/Gasoline Sulfur rule. The results indicate that improvements to residential visibility provide an economic benefit of $581 million dollars for the continental U.S.[26] A complete presentation of this method can be found in the benefits TSD for this RIA (Abt Associates, 1999).

One major source of uncertainty for the visibility benefit estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for willingness to pay for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small, or outside the range covered in the Chestnut and Rowe study, could also affect the results.

[26] The McClelland et al. (1990) study examined visibility changes in two Eastern cities, Chicago and Atlanta. Transferring these values to residential visibility changes in the Western U.S. may introduce greater uncertainty than transferring the values to other Eastern cities. As such, an additional alternate calculation showing the value of residential visibility just for the Eastern U.S. is included in Table VII-18.

2. Agricultural and Forestry Benefits

Reduced levels of ground-level ozone resulting from the final Tier 2/Gasoline Sulfur rule will have generally beneficial results on agricultural crop yields and commercial forest growth. Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of farmers' planting decisions, yield response functions, and agricultural supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs.

The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using the AGSIM© agricultural benefits model (Taylor et al., 1993). AGSIM© is an econometric-simulation model that is based on a large set of statistically estimated demand and supply equations for agricultural commodities produced in the United States. The model is capable of analyzing the effects of changes in policies (in this case, the implementation of the final Tier 2/Gasoline Sulfur rule) that affect commodity crop yields or production costs[27]. The benefits TSD for this RIA also provides further details on AGSIM© (Abt Associates, 1999).

The measure of benefits calculated by the model is the net change in consumer and producer surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of particular standards. Using the baseline and post-control equilibria, the model calculates the change in net consumer and producer surplus on a crop-by-crop basis[28]. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with the final Tier 2/Gasoline Sulfur rule.

The model employs biological exposure-response information derived from controlled experiments conducted by the National Crop Loss Assessment Network (NCLAN, 1996). For the purpose of our analysis, we analyze changes for the six most economically significant crops for which dose-response functions are available: corn, cotton, peanuts, sorghum, soybean, and winter wheat.[29] For some crops there are multiple dose-response functions, some more sensitive to ozone and some less. Our primary estimate assumes that crops are evenly mixed between relatively sensitive and relatively insensitive varieties. The primary estimate of the net change in economic surplus resulting from changes in ozone associated with the Tier 2/Gasoline Sulfur rule

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[27]AGSIM© is designed to forecast agricultural supply and demand out to 2010. We were not able to adapt the model to forecast out to 2030. Instead, we apply percentage increases in yields from decreased ambient ozone levels in 2030 to 2010 yield levels, and input these into a agricultural sector model held at 2010 levels of demand and supply. It is uncertain what impact this assumption will have on net changes in surplus.

[28] Agricultural benefits differ from other health and welfare endpoints in the length of the assumed ozone season. For agriculture, the ozone season is assumed to extend from April to September. This assumption is made to ensure proper calculation of the ozone statistic used in the exposure-response functions. The only crop affected by changes in ozone during April is winter wheat.

[29] The total value for these crops in 1997 was $57 billion.

is $217 million.

Similar models exist for forest products. Ozone also has been shown conclusively to cause discernible injury to forest trees (Fox and Mickler, 1996). Once the effects of changes in ozone concentrations on tree growth are predicted, econometric models of forest product supply and demand can be used to estimate changes in prices, producer profits and consumer surplus. Our analysis does not attempt to quantify commercial forestry benefits due to difficulties in obtaining C-R functions relating ozone exposure and tree growth. An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 1996c, p. 5-521). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals (Abt Associates, 1995), both by private property owners/tenants and by governmental units responsible for public areas. This is therefore a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

The final Tier 2/Gasoline Sulfur rule, by reducing NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (U.S. EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (U.S. EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

3. Benefits from Reductions in Materials Damage

The final Tier 2/Gasoline Sulfur rule is expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Criteria pollutants also have corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefit analyses including that for the Tier 2 Proposal RIA, have been able to provide quantitative estimates of household soiling damage. Following an SAB recommendation (EPA-SAB-Council-ADV-003, 1998), EPA has determined that the existing data (based on consumer expenditures from the early 1970's) is too out of date to provide a reliable enough estimate of current household soiling damages. However, a calculation is made for inclusion in the alternative calculations table (Table VII-18).

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits.

4. Benefits from Reduced Ecosystem Damage

The effects of air pollution on the health and stability of ecosystems are potentially very important, but are at present poorly understood and difficult to measure. The reductions in NO_X caused by the final rule could produce significant benefits. Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Haire et al., 1992).

Reductions in nitrogen loadings are estimated for twelve eastern estuaries (including two on the Gulf Coast). These estimated reductions are described earlier in this Chapter. Four of these estuaries have established consensus goals for reductions in annual nitrogen loads, indicating an intention of reaching these goals through implementation of controls on nitrogen sources. These four estuaries and their reduction goals are listed in Table VII-13.

Table VII-13. Reduction Goals and Nitrogen Loads to Selected Eastern Estuaries (tons per year)

Estuary	*Total Nitrogen Loadings*	*Nitrogen Loadings from Atmospheric Deposition*	*Overall Reduction Goal*
Albemarle/Pamlico Sound	25,300	11,000	7,600
Chesapeake Bay	185,000	49,500	35,600
Long Island Sound	53,700	13,200	31,460
Tampa Bay	3,900	2,100	100

Source: U.S. EPA, 1998

Estimated reductions in deposition of atmospheric nitrogen to these four estuaries are listed in Table VII-14, along with the percentage of the reduction goal accounted for by these reductions. These figures suggest that the reductions in nitrogen deposition resulting from the final Tier 2/Gasoline Sulfur rule will provide significant progress towards meeting nitrogen reduction goals in several of these estuaries.

Table VII-14. Estimated Annual Reductions in Nitrogen Loadings in Selected Eastern Estuaries for the Final Tier 2/Gasoline Sulfur Rule in 2030 (tons per year)

Estuary	*Change in Nitrogen Loadings*	*% of Estuary Nitrogen Reduction Goal*
Albemarle/Pamlico Sound	-2,013	26.5%
Chesapeake Bay	-3,080	8.7%
Long Island Sound	-1,144	3.6%
Tampa Bay[a]	-484	over 100%

[a] Tampa Bay had a very low nitrogen loadings reduction goal. As such, the Tier 2 rule provides more reductions than are necessary to achieve the stated goal.

Direct C-R functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP based measure of benefits depends on the availability of these C-R functions and on estimates of the value of environmental responses. Because neither appropriate C-R functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible. As stated earlier, an alternative is to use an avoided cost approach to estimate the welfare effects of PM on estuarine ecosystems. The use of the avoided cost approach to establish the value of a reduction in nitrogen deposition is problematic if there is not a direct link between reductions in air deposited nitrogen and the abandonment of a costly regulatory program. However, there are currently no readily available alternatives to this approach.

Based on the advice of the EPA Science Advisory Board, we use the avoided cost approach only to derive an alternative calculation of the value of reductions in atmospheric nitrogen loadings to estuaries (EPA-SAB-COUNCIL-ADV-00-002, 1999). The SAB believes that the avoided cost approach for nitrogen loadings is valid only if the state and local governments have established firm pollution reduction targets, and that displaced costs measured in the study represent measures not taken because of the CAAA (EPA-SAB-COUNCIL-ADV-00-002, 1999). Because the nitrate reduction targets in the studied estuaries are not firm targets, and there is not assurance that planned measures would be undertaken in the absence of the CAAA, we are currently unable to provide a meaningful primary estimate. However, the avoided cost estimate is presented in the table of alternative calculations (Table VII-18).

If better models of ecological effects can be defined, EPA believes that progress can be made in estimating WTP measures for ecosystem functions. These estimates would be superior to avoided cost estimates in placing economic values on the welfare changes associated with air pollution damage to ecosystem health. For example, if nitrogen or sulfate loadings can be linked to measurable and definable changes in fish populations or definable indexes of biodiversity, then CVM studies can be designed to elicit individuals' willingness to pay for changes in these effects. This is an important area for further research and analysis, and will require close collaboration among air quality modelers, natural scientists, and economists.

5. Estimated Values for Welfare Endpoints

Applying the valuation methods described above to the estimated changes in ozone and PM in 2030 yields estimates of the value of changes in visibility and agricultural yields. These estimates are presented in Table VII-15. All of the monetary benefits are in constant 1997 dollars.

We are unable to provide primary monetized estimates of residential visibility, household soiling, materials damage, nitrogen deposition and commercial forestry benefits, in addition to the other welfare effects listed in Table VII-1. These unmonetized benefits are indicated by placeholders, labeled B_3 to B_9. The estimate of total monetized welfare benefits is thus equal to the subset of monetized welfare benefits plus $\mathbf{B_W}$, the sum of the unmonetized welfare benefits.

Total monetized welfare related benefits are around $590 million. Monetized welfare benefits are roughly one fortieth the magnitude of monetized health benefits. However, due to the difficulty in quantifying and monetizing welfare benefits, a higher proportion of welfare benefits

Table VII-15. Estimated Annual Monetary Values for Welfare Effects Associated With Improved Air Quality Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	*Monetary Benefits (millions 1997$)*[a]
PM-related Endpoints	
Recreational Visibility (86 Class I areas in California, the Southeast and the Southwest)	$370
Residential Visibility	B_5
Household Soiling	B_6
Materials Damage	B_7
Nitrogen Deposition to Estuaries	B_8
Other PM-related welfare effects[b]	B_9
Ozone-related Endpoints	
Commercial Agricultural Benefits (6 major crops)	$220
Commercial Forestry Benefits	B_{10}
Other ozone-related welfare effects[b]	B_{11}
CO-related welfare effects[b]	B_{12}
HAPS-related welfare effects[b]	B_{13}
Total Monetized Welfare-related Benefits[c]	$590+$\mathbf{B_W}$

[a] Rounded to the nearest 10 million.
[b] A detailed listing of unquantified PM, ozone, CO, and HAPS related welfare effects is provided in Table VII-1.
[c] $\mathbf{B_W}$ is equal to the sum of all unmonetized welfare categories, i.e. $B_5+B_6+...+B_{13}$.

are not monetized. It is thus inappropriate to conclude that welfare benefits are unimportant just by comparing the estimates of the monetized benefits.

Alternative calculations for recreational visibility, residential visibility, household soiling, and nitrogen deposition are presented in Table VII-18 later in this chapter.

F. Total Benefits

We provide our preferred estimate of benefits for each health and welfare endpoint and the resulting preferred estimate of total benefits. To obtain this estimate, we aggregate dollar benefits associated with each of the effects examined, such as hospital admissions, into a total benefits estimate assuming that none of the included health and welfare effects overlap. The point estimate of the total benefits associated with the health and welfare effects is the sum of the separate effects estimates. Total monetized benefits associated with the final Tier 2/Gasoline Sulfur rule are listed in Table VII-16, along with a breakdown of benefits by endpoint. Note that the value of endpoints known to be affected by ozone and/or PM that we are not able to monetize are assigned a placeholder value, e.g. B_1, B_2, etc. Unquantified physical effects are indicated by a U. The estimate of total benefits is thus the sum of the monetized benefits and a constant, B, equal to the sum of the unmonetized benefits, $B_1+B_2+...+B_n$.

A comparison of the incidence column to the monetary benefits column reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects.

Our preferred estimate of total monetized benefits for the final Tier 2/Gasoline Sulfur rule is $25 billion, of which $23 billion is the benefits of reduced premature mortality risk from PM exposure. Total monetized benefits are dominated by the benefits of reduced mortality risk. Mortality related benefits account for over 90 percent of total monetized benefits followed by chronic bronchitis (3 percent). However, the adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community within and outside the Administration. In response to the sensitivity on this issue, we provide estimates reflecting two alternative approaches. The first approach -- supported by some in the above community and preferred by EPA -- uses a Value of a Statistical Life (VSL) approach developed for the Clean Air Act Section 812 benefit-cost studies. This VSL estimate of $5.9 million (1997$) was derived from a set of 26 studies identified by EPA using criteria established in Viscusi (1992), as those most appropriate for environmental policy analysis applications.

An alternative, age-adjusted approach is preferred by some others in the above community both within and outside the Administration. This approach was also developed for the Section 812 studies and addresses concerns with applying the VSL estimate –reflecting a valuation derived mostly from labor market studies involving healthy working-age manual laborers– to PM-related mortality risks that are primarily associated with older populations and those with impaired health status. This alternative approach leads to an estimate of the value of a statistical life year (VSLY), which is derived directly from the VSL estimate. It differs only in incorporating an explicit assumption about the number of life years saved and an implicit assumption that the valuation of each life year is not affected by age.[30] The mean VSLY is

[30] Specifically, the VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This annual average value of a life-year is then multiplied times the number of years of remaining life expectancy for the affected population (in the case of PM-related premature mortality, the average number of $ life-years saved is 14.

$360,000 (1997$); combining this number with a mean life expectancy of 14 years yields an age-adjusted VSL of $3.6 million (1997$).

Both approaches are imperfect, and raise difficult methodological issues which are discussed in depth in the recently published Section 812 Prospective Study, the draft EPA Economic Guidelines, and the peer-review commentaries prepared in support of each of these documents. For example, both methodologies embed assumptions (explicit or implicit) about which there is little or no definitive scientific guidance. In particular, both methods adopt the assumption that the risk versus dollars trade-offs revealed by available labor market studies are applicable to the risk versus dollar trade-offs in an air pollution context.

EPA currently prefers the VSL approach because, essentially, the method reflects the direct, application of what EPA considers to be the most reliable estimates for valuation of premature mortality available in the current economic literature. While there are several differences between the labor market studies EPA uses to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. For example, adjusting for age differences may imply the need to adjust the $5.9 million VSL downward as would adjusting for health differences, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $5.9 million value while acknowledging the significant limitations and uncertainties in the available literature. Furthermore, EPA prefers not to draw distinctions in the monetary value assigned to the lives saved even if they differ in age, health status, socioeconomic status, gender or other characteristic of the adult population.

Those who favor the alternative, age-adjusted approach (i.e. the VSLY approach) emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $5.9 million (1997 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies - as is the case here - they prefer to adjust the VSL estimate to reflect those differences. While acknowledging that the VSLY approach provides an admittedly crude adjustment (for age though not for other possible differences between the populations), they point out that it has the advantage of yielding an estimate that is not presumptively biased. Proponents of adjusting for age differences using the VSLY approach fully concur that enormous uncertainty remains on both sides of this estimate - upwards as well as downwards - and that the populations differ in ways other than age (and therefore life expectancy). But rather than waiting for all relevant questions to be answered, they prefer a process of refining estimates by incorporating new information and evidence as it becomes available.

The estimates of benefits for the final Tier 2/Gasoline Sulfur rule using the different approaches for premature mortality valuation are presented in Table VII-17. The VSL approach –the approach EPA prefers – yields a monetized benefit estimate of $25.5 billion. The alternative, age-adjusted approach yields monetary benefits of $14 billion. The final Tier 2/Gasoline Sulfur rule is expected to affect populations in the entire continental U.S[31]. Given a projected U.S. population in 2030 of 300 million, annual monetized per capita benefits (using EPA's preferred approach for valuing reductions in premature mortality) are over $84 in 2030. Assuming an average household size of 2.6 persons, this translates to over $218 per household in 2030.

[31] The Tier 2/Gasoline Sulfur standards will not apply to vehicles in California, however, populations in California are expected to receive some benefits from the Tier 2/Gasoline Sulfur standards due to reductions in pollutants transported into the state from other regions.

Table VII-16. EPA Preferred Estimate of Annual Quantified and Monetized Benefits Associated With Improved Air Quality Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	*Pollutant*	*Avoided Incidence[c,d] (cases/year)*	*Monetary Benefits[e] (millions 1997$)*
Premature mortality[a,h] (adults, 30 and over)	PM[b]	4,300	$23,380
Chronic asthma (adult males, 27 and over)	Ozone	400	$10
Chronic bronchitis	PM	2,300	$730
Hospital Admissions from Respiratory Causes	Ozone and PM	2,200	$20
Hospital Admissions from Cardiovascular Causes	Ozone and PM	800	$10
Emergency Room Visits for Asthma	Ozone and PM	1,200	$<1
Acute bronchitis (children, 8-12)	PM	7,900	$<1
Lower respiratory symptoms (children, 7-14)	PM	87,100	$<5
Upper respiratory symptoms (asthmatic children, 9-11)	PM	86,500	$<5
Shortness of breath (African American asthmatics, 7-12)	PM	17,400	$<1
Work loss days (adults, 18-65)	PM	682,900	$70
Minor restricted activity days /Acute resp. symptoms	Ozone and PM	5,855,000	$270
Other health effects[d]	Ozone, PM, CO, HAPS	$U_1+U_2+U_3+U_4$	$B_1+B_2+B_3+B_4$
Decreased worker productivity	Ozone	—	$140
Recreational visibility (86 Class I Areas)	PM	—	$370
Residential visibility	PM	—	B_5
Household soiling damage	PM	—	B_6
Materials damage	PM	—	B_7
Nitrogen Deposition to Estuaries	Nitrogen	—	B_8
Agricultural crop damage (6 crops)	Ozone	—	$220
Commercial forest damage	Ozone	—	B_9
Other welfare effects[f]	Ozone, PM, CO, HAPS	—	$B_{10}+B_{11}+B_{12}+B_{13}$
Monetized Total[g,h]			$25,220+**B**

[a] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the valuation assumes the 5 year distributed lag structure described earlier.
[b] PM reductions are due to reductions in NOx and SO_2 resulting from the Tier 2/Gasoline Sulfur rule.
[c] Incidences are rounded to the nearest 100.
[d] The U_i are the incidences for the unquantified category i.

[e] Dollar values are rounded to the nearest 10 million.
[f] A detailed listing of unquantified PM, ozone, CO, and HAPS related heatlh and welfare effects is provided in Table VII-1.
[g] **B** is equal to the sum of all unmonetized categories, i.e. $B_1+B_2+...+B_{13}$.
[h] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach. This approach and an alternative, age-adjusted approach – the VSLY approach – are discussed more fully in section F.

Table VII-17. Final Tier 2/Gasoline Sulfur Rule: 2030 Monetized Benefits Estimates for Alternative Premature Mortality Valuation Approaches (Billions of 1997 dollars)

Premature Mortality Valuation Approach	*PM Mortality Benefits*	*Total Monetized Benefits*
Value of statistical life (VSL) ($5.9 million per life saved)[a]	$23.4	$25.2 + **B**
Value of statistical life-years (VSLY) ($360,000 per life-year saved, which implies $3.6 million per life saved, based on the mean of 14 life-years saved)[a, b]	$11.9	$13.7 + **B**

[a] Premature mortality estimates are determined assuming a 5 year distributed lag, which applies 25 percent of the incidence in year 1 and 2, and then 16.7 percent of the incidence in years 3, 4, and 5.
[b] The VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies used to obtain the VSL estimate. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This approach is discussed more fully in section F above.

In addition to the preferred estimate, in Table VII-18 we present alternative calculations representing how the value for individual endpoints or total benefits would change if we were to make a different assumption about an element of the benefits analysis. For example, this table can be used to answer questions like "What would total benefits be if we were to use the Dockery, et al. C-R function to estimate avoided premature mortality?" This table provides alternative calculations both for valuation issues (e.g. the correct value for a statistical life saved) and for physical effects issues (e.g., how reversals in chronic illnesses are treated). This table is not meant to be comprehensive. Rather, it reflects some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. Accompanying Table VII-18 is a brief discussion of each of the alternative calculations.

While Table VII-18 provides alternative calculations for specific alternative assumptions, there are some parameters to which total benefits may be sensitive but for which no or limited credible scientific information exists to determine plausible values. Sensitivity analyses for these parameters are presented in Appendix VII-A. Issues examined in this appendix include alternative specifications for the lag structure of PM related premature mortality and impacts of assumed thresholds on the estimated incidence of avoided premature mortality. Also, this appendix contains several illustrative endpoint calculations for which the scientific uncertainty is too great to provide a reasonable estimate for which inclusion would lead to double-counting of benefits. These include premature mortality associated with daily fluctuations in PM, infant mortality associated with PM, and premature mortality associated with daily fluctuations in ozone.

We have simulated a distribution around our preferred estimate to characterize uncertainty in the total benefit estimate due to measurement uncertainty (i.e. variance of estimated C-R functions and valuation functions) holding all other potentially uncertain inputs constant. Based on the simulated distribution, we have included calculations of the 5th and 95th percentiles of the distribution of benefits in Table VII-18. This provides an estimate of how sensitive the preferred estimate of total benefits would be to measurement errors (i.e. statistical uncertainty around C-R and valuation functions) if all other factors could be treated as certain. However, these do not represent the actual range of benefits, given the large number of uncertain factors for which we are not able to provide uncertainty estimates. In most cases the effect of the uncertainty on total benefits is unknown (i.e., it could increase or decrease benefits depending on specific conditions).

Table VII-18. Alternative Benefits Calculations for the Tier 2/Gasoline Sulfur Rule in 2030

Alternative Calculation	*Description of Estimate*	*Impact on Preferred Benefit Estimate (million 1997$)*
5^{th} percentile of “measurement” uncertainty distribution	Estimate of total monetized benefits at the 5^{th} percentile of a distribution generated using Monte Carlo simulation assuming measurement error is the only source of uncertainty in the benefits estimates.	-$20,300 (-81%)
95^{th} percentile of “measurement” uncertainty distribution	Estimate of total monetized benefits at the 95^{th} percentile of a distribution generated using Monte Carlo simulation assuming measurement error is the only source of uncertainty in the benefits estimates.	+$33,900 (+134%)
PM-related premature mortality based on Dockery et al.	The Dockery et al. study provides an alternative estimate of the relationship between chronic PM exposure and mortality. The number of avoided mortality incidences increases from 4,300 to 9,800 (128%)	+$30,200 (+120%)
Value of avoided premature mortality incidences based on statistical life years.	Calculate the incremental number of life-years lost from exposure to changes in ambient PM and use the value of a statistical life year based on a $5.9 million value of a statistical life	-$11,500 (-46%)
Reversals in chronic bronchitis treated as lowest severity cases	Instead of omitting those cases of chronic bronchitis that reverse after a period of time, they are treated as being cases with the lowest severity rating. The number of avoided chronic bronchitis incidences increases from 2,300 to 4,300 (87%)	+$280 (+1%)
Value of visibility changes in all Class I areas	Values of visibility changes at Class I areas in California, the Southwest, and the Southeast are transferred to visibility changes in Class I areas in other regions of the country.	+$180 (+1%)
Value of visibility changes in Eastern U.S. residential areas	Value of visibility changes outside of Class I areas are estimated for the Eastern U.S. based on the reported values for Chicago and Atlanta from McClelland, et al. (1990)	+$420 (+2%)
Value of visibility changes in Western U.S. residential areas	Values of visibility changes outside of Class I areas are estimated for the Western U.S. based on the reported values for Chicago and Atlanta derived from McClelland et al. (1990)	+$130 (+1%)
Household soiling damage	Value of decreases in expenditures on cleaning are estimated using values derived from Manuel, et al. (1983)	+$110 (+1%)

Alternative Calculation	*Description of Estimate*	*Impact on Preferred Benefit Estimate (million 1997$)*
Avoided costs of reducing nitrogen loadings in east coast estuaries	Estuarine benefits in 12 east coast estuaries from reduced atmospheric nitrogen deposition are approximated using the avoided costs of removing or preventing loadings from terrestrial sources.	+$160 (+1%)

The 5th and 95th percentile alternative calculations (rows 1 and 2 of Table VII-18) are estimated by holding air quality changes, population estimates, and other factors, including the parameters examined in Table VII-18, constant and determining the distribution of total benefits that would be generated by a large number of random draws from the distributions of C-R functions and economic valuation functions. These alternative calculations thus show how the preferred estimate of benefits changes in response to uncertainty in the measurement of C-R and valuation functions.

The Dockery, et al. estimate of the relationship between PM exposure and premature mortality (row 3 of Table VII-18) is a plausible alternative to the Pope, et al. The SAB has noted that "the study had better monitoring with less measurement error than did most other studies" (EPA-SAB-COUNCIL-ADV-99-012, 1999). However, the Dockery study had a more limited geographic scope (and a smaller study population) than the Pope, et al. study. The demographics of the Pope,et al. study population, i.e. largely white and middle-class, may also produce a downward bias in the Pope PM mortality coefficient, because short-term studies indicate that the effects of PM tend to be significantly greater among groups of lower socioeconomic status. The Dockery study also covered a broader age category (25 and older compared to 30 and older in the Pope study) and followed the cohort for a longer period (15 years compared to 8 years in the Pope study). For these reasons, the Dockery study is considered to be a plausible alternative estimate of the avoided premature mortality incidences associated with the final Tier 2/Gasoline Sulfur rule.

The value of statistical life years alternative calculation (row 4 of Table VII-18) recognizes that individuals who die from air pollution related causes tend to be older than the average age of individuals in the VSL studies used to develop the $5.9 million value.

The treatment of reversals in chronic bronchitis incidences is addressed in row 5 of Table VII-18. Reversals are defined as those cases where an individual reported having chronic bronchitis at the beginning of the study period but reported not having chronic bronchitis in follow-up interviews at a later point in the study period. Since, by definition, chronic diseases are long-lasting or permanent, if the disease goes away it is not chronic. However, we have not captured the benefits of reducing incidences of bronchitis that are somewhere in-between acute and chronic. One way to address this is to treat reversals as cases of chronic bronchitis that are at the lowest severity level. These cases thus get the lowest value for chronic bronchitis.

The alternative calculation for recreational visibility (row 6 of Table VII-18) is an estimate of the full value of visibility in the entire region affected by the final Tier 2/Gasoline Sulfur rule. The Chestnut and Rowe study from which the primary valuation estimates are derived only examined WTP for visibility changes in the southeastern portion of the affected region. In order to obtain estimates of WTP for visibility changes in the northeastern and central portion of the affected region, we have to transfer the southeastern WTP values. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region, is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions[20] A complete discussion of the benefits transfer method used to generate this alternative estimate is provided in the benefits TSD for this RIA (Abt Associates, 1999)

The alternative calculation for residential visibility (row 7 of Table VII-18) is based on the McClelland, et al. study of WTP for visibility changes in Chicago and Atlanta. As discussed in section F.1, the residential visibility estimates from the available literature have been determined by the SAB to be inadequate for use in a primary estimate in a benefit-cost analysis. However, EPA recognizes that residential visibility is likely to have some value and the McClelland, et al. estimates are the most useful in providing an estimate of the likely magnitude of the benefits of residential visibility improvements.

The alternative calculation for household soiling (row 8 of Table VII-18) is based on the Manuel et al. study of consumer expenditures on cleaning and household maintenance. This study has been cited as being “the only study that measures welfare benefits in a manner consistent with economic principals (Desvouges et al., 1998). However, the data used to estimate household soiling damages in the Manuel, et al. study is from a 1972 consumer expenditure survey and as such may not accurately represent consumer preferences in 2007. EPA recognizes this limitation, but believes the Manuel, et al. estimates are still useful in providing an estimate of the likely magnitude of the benefits of reduced household soiling by particulate matter.

The alternative calculation for the avoided costs of reductions in nitrogen loadings (row 9 of Table VII-18) is constructed by examining the avoided costs to surrounding communities of reduced nitrogen loadings for three case study estuaries (EPA, 1998).[21] The three case study estuaries are chosen because they have agreed upon nitrogen reduction goals and the necessary nitrogen control cost data. The values of atmospheric nitrogen reductions are determined on the basis of avoided costs associated with agreed upon controls of nonpoint water pollution sources. Benefits are estimated using a weighted-average, locally-based cost for nitrogen removal from water pollution (U.S. EPA, 1998a). Valuation reflects water pollution control cost avoidance based on the weighted average cost/pound of current non-point source water pollution controls for nitrogen in the three case study estuaries. Taking the weighted cost/pound of these available controls assumes States will combine low cost and high cost controls, which could inflate avoided cost estimates. The avoided cost measure is likely to be an underestimate of the value of reduced nitrogen loadings in eastern estuaries because: 1) the twelve estuaries represent only about fifty percent of the total watershed area in the eastern U.S.; and 2) costs avoided are not good proxies for willingness-to-pay. The details of the nitrogen deposition benefits calculation are provided in the benefits TSD for this RIA (Abt Associates, 1999).

G. Summary of Cost Results

Since the benefits assessment has been performed on the basis of a 2030 fleet of Tier 2 vehicles, consistent costs were developed using the same basis. For this purpose we used the long term cost once the capital costs have been recovered and the manufacturing learning curve reductions have been realized, since this most closely represents the makeup of a 2030 fleet.

This analysis also made adjustments in the costs to account for the fact that there is a time difference between when some of the costs are expended and when the benefits are realized. The vehicle costs are expended when the vehicle is sold, while the fuel related costs and the benefits are distributed over the life of the vehicle.

We resolved this difference by using costs distributed over time such that there is a constant cost per ton of emissions reduction and such that the net present value of these distributed costs corresponds to the net present value of the actual costs. A constant ratio of cost to emission reduction over the life of the vehicle would also reflect itself in the ratio of the net present value of the costs and net present value of the emission reductions. This, of course, is how EPA determined the cost effectiveness estimates for the proposed rule. Thus, the simplest way to develop this distributed cost number is to multiply the cost effectiveness ratio (dollars per ton) times the emission reduction estimates for the benefits assessment.

The cost-effectiveness value that was used in our calculation of applicable costs was calculated as the ratio of the net present value of vehicle and fuel costs divided by the net present value of emission reductions for an average vehicle meeting our Tier 2 standards, as described in Section VI. However, the cost-effectiveness value used for our benefit-cost analysis differed in several ways from those in Table VI-8. These differences ensured that the cost-effectiveness value represented the same set of assumptions that were used when we developed the emission inventories for use in the air quality modeling that formed the basis of the benefits analysis. Specifically, we did not include the larger LDT4 trucks weighing greater than 8500 lb GVWR, and we did not include any effects of catalyst irreversibility. We also focused on the "long-term" cost-effectiveness as described above, since this value best represents the cost-effectiveness in

2030.

Finally, adjustments for two factors relating to fuel consumption needed to be made to enable us to arrive at a final value for the adjusted cost. First the cost effectiveness value we calculated did not account for the approximately 20 percent drop in the per-gallon fuel cost occurring about 2020 (due to the lowering cost of desulfurization technology discussed in Chapter V). Second, our cost effectiveness value also did not include the effects of expected improvements in fleet fuel economy prior to 2020, also discussed in Chapter V. Improvements in light duty truck and passenger car fuel economy are expected to reduce 2020 and beyond per-mile fuel consumption by a little over 10 percent compared to that used in our cost effectiveness calculation. Adjustments to account for the impact of these factors on total cost are included in the table below.

There is one factor related to calculation of the adjusted cost which we were not able to quantitatively account for in this analysis. This relates to the increasing rate of mileage accumulation per vehicle over time. Fleet wide VMT is generally growing faster than vehicle sales, indicating a gradual growth in VMT per vehicle. However, our per-vehicle cost effectiveness is based on the current distribution of VMT with age of the vehicle, providing a conservative basis for our cost-effectiveness calculations. By 2030, this assumption is likely to yield substantially higher cost-effectiveness values than are appropriate. At this time we have no specific estimate of the impact of this growth in per-vehicle VMT, so no adjustment has been made to account for its existence. The adjusted cost would be lower if this factor were accounted for.

The resulting adjusted costs are somewhat greater than the actual annual cost of the program, reflecting the time value adjustment and lack of correction for the increase in VMT per vehicle. Thus, the costs presented in this section do not represent actual annual costs of the Tier 2/gasoline sulfur program for 2030. Rather, they represent an approximation of the steady-state cost per ton that would likely prevail in that time period. Except for the VMT adjustment, the benefit-cost ratio for the earlier years of the program would be expected to be lower than that based on these costs, since the per-vehicle costs are larger in the early years of the program while the benefits are smaller. The resulting adjusted cost value is given in Table VII-19.

Table VII - 19. Adjusted Cost for Comparison to Benefits

Cost per ton ratio	*fuel cost adjustment*	*fuel economy adjustment*	*Tons of NOx + NMHC*	*Adjusted Cost (billions of 1997 dollars)*
$2,107	0.87	0.9	3,204,600	$5.3

I. Comparison of Costs and Benefits

Benefit-cost analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, benefit-cost analysis helps illuminate important potential effects of alternative policies and helps set priorities for closing information gaps and reducing uncertainty. According to economic theory, the efficient alternative policy maximizes net benefits to society (i.e., social benefits minus social costs). However, not all relevant costs and benefits can be captured in any analysis. Executive Order 12866 clearly indicates that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. There are many important unquantified and unmonetized costs and benefits associated with reductions in emissions, including many health and welfare effects. Potential benefit categories that have not been quantified and monetized are listed in Table VII-1 of this chapter.

In addition to categories that cannot be included in the calculated net benefits, there are also practical limitations for the comparison of benefits to costs in this analysis, which have been discussed throughout this chapter. Several specific limitations deserve to be mentioned again here:

- The state of atmospheric modeling is not sufficiently advanced to provide a workable "one atmosphere" model capable of characterizing ground-level pollutant exposure for all pollutants of interest (e.g., ozone, particulate matter, carbon monoxide, nitrogen deposition, etc). Therefore, the EPA must employ several different pollutant models to characterize the effects of alternative policies on relevant pollutants. Also, not all atmospheric models have been widely validated against actual ambient data. In particular, since a broad-scale monitoring network does not yet exist for fine particulate matter ($PM_{2.5}$), atmospheric models designed to capture the effects of alternative policies on $PM_{2.5}$ are not fully validated. Additionally, significant shortcomings exist in the data that are available to perform these analyses. While containing identifiable shortcomings and uncertainties, EPA believes the models and assumptions used in the analysis are reasonable based on the available evidence.

- Another dimension adding to the uncertainty of this analysis is time. Thirty years is a very long time over which to carry assumptions. Projected growth in population and VMT over the 30-year period may have a significant effect on the benefits estimates. Pollution control technology has advanced considerably in the last 10 years and can be expected to continue to advance in the future. Yet there is no clear way to model this advance for use in this analysis. In addition, there is no clear way to predict future meteorological conditions, or the growth in emissions from other sources over time. Again, EPA believes that the assumptions to capture these elements are reasonable based on the available evidence.

- Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in detail in earlier sections. Where information and data exist, quantitative characterizations of these uncertainties are included (in this chapter and in Appendix VII-A). However, data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

- The preferred benefit estimate does not include the monetary value of several known ozone and PM-related welfare effects, including commercial forest growth, residential visibility, household soiling and materials damage, and deposition of nitrogen to sensitive estuaries.

Nonetheless, if one is mindful of these limitations, the relative magnitude of the benefit-cost comparison presented here can be useful information. Thus, this section summarizes the benefit and cost estimates that are potentially useful for evaluating the efficiency of the final Tier 2 rulemaking.

The estimated adjusted cost of implementing the final Tier 2 program is **$5.3 billion (1997$)**, while the estimate of monetized benefits using EPA's preferred approach for monetizing reductions in PM-related premature mortality – the VSL approach – are **$25.2 billion (1997$).** Monetized net benefits using EPA's preferred method for valuing avoided incidences of premature mortality are approximately **$19.9 billion (1997$).** Using the alternative, age-adjusted approach – the VSLY approach – total monetized benefits are projected to be around **$13.8 billion (1997$)**. Monetized net benefits using this approach are approximately **$8.5 billion (1997$)**. Therefore, implementation of the Tier 2 program will provide society with a net gain in social welfare. Tables VII-20 and VII-21 summarize the costs, benefits, and net benefits for the two alternative valuation approaches.

Table VII-20. 2030 Annual Monetized Costs, Benefits, and Net Benefits for the Final Tier 2/Gasoline Sulfur Rule: EPA Preferred Estimates Using the Value of Statistical Lives Saved Approach to Value Reductions in Premature Mortality[a]

	Billion 1997$
Adjusted compliance costs	\$5.3
Monetized PM-related benefits[b,d]	\$24.7+$\mathbf{B}_{\mathbf{PM}}$
Monetized Ozone-related benefits[b]	\$0.5+$\mathbf{B}_{\mathbf{Ozone}}$
Monetized net benefits[c,d]	\$19.9+**B**

[a] For this section , all costs and benefits are rounded to the nearest 100 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.
[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in **Table VII-1.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.
[c] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HAPS.
[d] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach. This approach and an alternative, age-adjusted approach – the VSLY approach – are discussed more fully in section F.

Table VII-21. 2030 Annual Monetized Costs, Benefits, and Net Benefits for the Final Tier 2/Gasoline Sulfur Rule: Alternative Estimates Using the Value of Statistical Life Years Saved Approach to Value Reductions in Premature Mortality[a]

	Billion 1997$
Adjusted compliance costs	\$5.3
Monetized PM-related benefits[b,d]	\$13.3+$\mathbf{B}_{\mathbf{PM}}$
Monetized Ozone-related benefits[b]	\$0.5+$\mathbf{B}_{\mathbf{Ozone}}$
Monetized net benefits[c,d]	\$8.5+**B**

[a] For this section , all costs and benefits are rounded to the nearest 100 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.
[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in **Table VII-1.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.
[c] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HAPS.
[d] The VSLY estimate is calculated by amortizing the \$5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies used to obtain the VSL estimate. The resulting estimate, using a 5 percent discount rate, is \$360,000 per life-year saved in 1997 dollars. This approach is discussed more fully in section F above.

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Appendix VII-A
Supplementary Benefit Estimates and Sensitivity Analyses of Key Parameters in the Benefits Analysis

A. Introduction and Overview

In chapter VII, we estimated the benefits of the final Tier 2/gasoline sulfur rule using the most comprehensive set of endpoints available. For some health endpoints, this meant using a dose-response function that linked a larger set of effects to a change in pollution, rather than using dose-response functions for individual effects. For example, the minor restricted activity days/any of 19 acute respiratory symptoms endpoint covers most of the symptoms used to characterize asthma attacks and days of moderate or worse asthma. For premature mortality, we selected a dose-response function that captured reductions in incidences due to both long and short-term exposures to ambient concentrations of particulate matter (PM). In addition, the premature mortality dose-response function is expected to capture at least some of the mortality effects associated with exposure to ozone. This effect is described more fully below in section A.2.

In order to provide the reader with a fuller understanding of the health effects associated with reductions in air pollution associated with the final Tier 2/gasoline sulfur rule, this appendix provides estimates for those health effects which, if included in the primary estimate, could result in double-counting of benefits. For some endpoints, such as ozone mortality, additional research is needed to provide separate estimates of the effects for different pollutants, i.e. PM and ozone. These supplemental estimates should not be considered as additive to the primary estimate of benefits. Supplemental estimates included in this appendix include premature mortality associated with short-term exposures to PM and ozone, asthma attacks, and occurrences of moderate or worse asthma symptoms. In addition, an estimate of the avoided incidences of premature mortality in infants is provided. Because the Pope, et al. estimate applies only to adults, avoided incidences of infant mortality are additive to the primary benefits estimate.

Table VII-19 in Chapter VII reports the results of alternative calculations based on plausible alternatives to the assumptions used in deriving the primary estimate of benefits. In addition to these calculations, two important parameters, the length and structure of the potential lag in mortality effects and thresholds in PM health effects, have been identified as key to the analysis, and are explored in this appendix through the use of sensitivity analyses.

B. Supplementary Benefit Estimates

In the primary estimate, we use the Pope et al. study to provide the C-R function relating premature mortality to long-term PM exposure. In the primary analysis, we assume that this mortality occurs over a five year period, with 25 percent of the deaths occurring in the first year, 25 percent in the second year, and 16.7 percent in each of the third, fourth, and fifth years. Studies examining the relationship between short-term exposures and premature mortality can reveal what proportion of premature mortality is due to immediate response to daily variations in PM. There is only one short-term study (presenting results from 6 separate U.S. cities) that uses $PM_{2.5}$ as the metric of PM (Schwartz et al., 1996). As such, the supplemental estimate for premature mortality related to short-term PM exposures is based on the pooled city-specific, short-term $PM_{2.5}$ results from Schwartz, et al.

In the Tier 2 Proposal RIA, we estimated avoided incidences of ozone-related premature mortality for the primary benefits estimate. Based on recent advice from the SAB (EPA-SAB-Council-ADV-99-012, 1999), we have converted this endpoint to a supplemental estimate to avoid potential double-counting of benefits captured by the Pope, et al. PM premature mortality endpoint[32]. There are many studies of the relationship between ambient ozone levels and daily mortality levels. The supplemental estimate is calculated using results from only four U.S. studies (Ito and Thurston, 1996; Kinney et al., 1995; Moolgavkar et al., 1995; and Samet et al., 1997), based on the assumption that demographic and environmental conditions on average would be more similar between these studies and the conditions prevailing when the Tier 2/gasoline sulfur rule is implemented. However, the full body of peer-reviewed ozone mortality studies should be considered when evaluating the weight of evidence regarding the presence of an association between ambient ozone concentrations and premature mortality. We combined these studies using probabilistic sampling methods to estimate the impact of ozone on mortality incidence. The technical support document for this analysis provides additional details of this approach (Abt Associates, 1999). The estimated incidences of short-term premature mortality are valued using the value of statistical lives saved method, as described in Chapter VII.

The estimated effect of PM exposure on premature mortality in infants (post neo-natal) is based on a single U.S. study (Woodruff, et al, 1997) which, on recommendation of the Science Advisory Board, was deemed too uncertain to include in the primary analysis. Adding this endpoint to the primary benefits estimate would result in an increase in total benefits.

[32]While the growing body of epidemiological studies suggests that there may be a positive relationship between ozone and premature mortality, there is still substantial uncertainty about this relationship. Because the evidence linking premature mortality and particulate matter is currently stronger than the evidence linking premature mortality and ozone, it is important that models of the relationship between ozone and mortality include a measure of particulate matter as well. Because of the lack of monitoring data on fine particulates or its components, however, the measure of particulate matter used in most studies was generally either PM10 or TSP or, in some cases, Black Smoke. If a component of PM, such as PM 2.5 or sulfates, is more highly correlated with ozone than with PM or TSP, and if this component is also related to premature mortality, then the apparent ozone effects on mortality could be at least partially spurious. Even if there is a true relationship between ozone and premature mortality, after taking particulate matter into account, there would be a potential problem of double counting in this analysis if the ozone effects on premature mortality were added to the PM effects estimated by Pope et al., 1995, because, as noted above, the Pope study does not include ozone in its model.

As noted in Chapter VII, asthma affects over seven percent of the U.S. population. One study identifies a statistical association between air pollution and the development of asthma in some non-smoking adult men. Other studies identify a relationship between air quality and occurrences of acute asthma attacks or worsening of asthma symptoms. Supplemental estimates are provided for two asthma related endpoints. Occurrence of moderate or worse asthma symptoms in adults is estimated using a C-R function derived from Ostro, et al. (1991). Asthma attacks in children are estimated using a C-R function derived from Whittemore and Korn (1980). Both asthma attacks and occurrence of moderate or worse asthma symptoms are valued at $39 per incidence, based on the mean of average WTP estimates for the four severity definitions of a “bad asthma day,” described in Rowe and Chestnut (1986), a study which surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day,” as defined by the subjects.

Table VII-A-1 presents estimated incidences and values for the supplemental endpoints listed above. The supplemental estimate of 1,200 avoided incidences of premature mortality from short-term exposures to PM indicates that these incidences are approximately 25 percent of the total premature mortality incidences estimated using the Pope, et al., study (4,300). This lends support for the assumption that 25 percent of the premature deaths predicted to be avoided in the first year using the Pope study should be assigned to the first year after a reduction in exposure.

The infant mortality estimate indicates that exclusion of this endpoint does not have a large impact, either in terms of incidences (13) or monetary value (approximately $80 million). Estimates of the value for separate asthma endpoints are well under the estimate of the value of all respiratory symptoms. All of these supplemental estimates support the set of endpoints and assumptions chosen as the basis of the primary benefits estimate described in Chapter VII.

Table VII-A-1
Supplemental Benefit Estimates for the Final Tier 2 Rule for the 2030 Analysis Year

Endpoint	*Pollutant*	*Avoided Incidence[a] (cases/year)*	*Monetary Benefits[b] (millions 1997$)*
Premature mortality (short-term exposures)	PM	1,200	$6,320
Premature mortality (short-term exposures)[c]	Ozone	500	$2,670
Premature mortality in infant population	PM	<100	$80
Asthma attacks	PM	77,000	$<10
Asthma attacks [c]	Ozone	188,100	$10
Moderate or Worse Asthma	PM	79,500	$<10

[a] Incidences are rounded to the nearest 100.
[b] Dollar values are rounded to the nearest 10.

C. Sensitivity Analyses

As discussed in Chapter VII, there are two key parameters of the benefits analysis for which there are no specific values recommended in the scientific literature. These parameters, the lag between changes in exposure to PM and reductions in premature mortality and the threshold in PM-related health effects, are investigated in this section through the use of sensitivity analyses, we perform an analysis of the sensitivity of benefits valuation to the lag structure by considering a range of assumptions about the timing of premature mortality. To examine the threshold parameter, we show how the estimated avoided incidences of PM-related premature mortality are distributed with respect to the threshold.

1. Alternative Lag Structures

As noted by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), "some of the mortality effects of cumulative exposures will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question." However, they also note that "Although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no a lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population." In the primary analysis, based on SAB advice, we assume that mortality occurs over a five year period, with 25 percent of the deaths occurring in the first year, 25 percent in the second year, and 16.7 percent in each of the third, fourth, and fifth years. Readers should note that the selection of a 5 year lag is not supported by any scientific literature on PM-related mortality. Rather it is intended to be a best guess at the appropriate distribution of avoided incidences of PM-related mortality.

Although the SAB recommended the five-year distributed lag be used for the primary analysis, the SAB has also recommended (EPA-SAB-COUNCIL-ADV-00-001, 1999) that alternative lag structures be explored as a sensitivity analysis. Specifically, they recommended an analysis of 0, 8, and 15 year lags. The 0 year lag is representative of EPA's assumption in previous RIAs. The 8 and 15 year lags are based on the study periods from the Pope and Dockery studies, respectively[33]. However, neither the Pope or Dockery studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope and Dockery studies do not contain any data either supporting or refuting the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8 and 15 year lags implicitly assume that all premature mortalities occur at the end of the study periods, i.e. at 8 and 15 years. We also present two additional lags: a 15 year distributed lag with the distribution skewed towards the early years and a 15 year distributed lag with the distribution skewed towards the later years. This is to demonstrate how sensitive the results are not only to the length of the lag, but also to the shape of the distribution of incidences over the lag period. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths, but rather the timing of those deaths.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope, et al. C-R function) are presented in Table VII-A-2. These estimates are based on the value of statistical lives saved approach, i.e. $5.9 million per incidence, and assume a 5 percent discount rate over the lag period. The results using the primary 5-year lag are repeated here for comparison. The table reveals that the length of the lag period is not as important as the distribution of incidences within the lag period. A 15 year distributed lag with most of the incidences occurring in the early years reduces monetary benefits less than an 8 year lag with all incidences occurring at the eighth year. Even with an extreme lag assumption of 15 years, benefits are reduced by less than half relative to the no lag and primary (5 year distributed lag) benefit estimates.

[33]Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects, but is more likely due to the expense of conducting long-term studies or the amount of satisfactory data that could be collected during this time period.

Table VII-A-2
Sensitivity Analysis of Alternative Lag Structures for PM-related Premature Mortality

Lag	*Description*	*Monetary Benefit (millions 1997$)*	*Percent of Primary Estimate*
5-year distributed	Primary estimate, incidences are distributed with 25% in the 1st and 2nd years, and 16.7% in the remaining 3 years.	$23,400	100%
None	Incidences all occur in the first year	$25,400	109%
8 year	Incidences all occur in the 8th year	$18,000	77%
15 year	Incidences all occur in the 15th year	$12,800	55%
15 year distributed - skewed early	Incidences are distributed with 30% in the 1st year, 25% in the 2nd year, 15% in the 3rd year, 6% in the 4th year, 4% in the 5th year, and the remainder 20% distributed over the last 10 years.	$22,700	97%
15 year distributed - skewed late	Incidences are distributed with 4% in the 11th year, 6% in the 12th year, 15% in the 13th year, 25% in the 14th year, and 30% in the 15th year, with the remaining 20 % distributed over the first 10 years.	$14,800	63%

2. PM Health Effect Threshold

In developing its primary estimate of benefits for previous analyses, EPA has assumed a PM health effects threshold equal to the lowest observed level in a given epidemiological study or anthropogenic background when no lowest observed level is reported (Hubbell, 1998). Recent advice from the SAB (EPA-SAB-Council-ADV-99-012, 1999) is that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM related health effects considered in this analysis. The most important health endpoint that would be impacted by a PM threshold is premature mortality, as measured by the Pope, et al. (1995) C-R function. Pope et al. did not explicitly include a threshold in their analysis. However, if the true mortality C-R relationship has a threshold, then Pope et al.'s slope coefficient would likely have been underestimated for that portion of the C-R relationship above the threshold. This would likely lead to an underestimate of the incidences of avoided cases above any assumed threshold level. It is difficult to determine the size of the underestimate without data on a likely threshold and without re-analyzing the Pope et al. data. Nevertheless, it is illustrative to show at what threshold levels benefits are significantly affected.

Any of the PM-related health effects estimated in the primary analysis could have a threshold; however a threshold for PM-related mortality would have the greatest impact on the overall benefits analysis. Figure A-1 shows the effect of incorporating a range of possible thresholds, using 2030 PM levels and the Pope et al. (1995) study.

The distribution of premature mortality incidences in Figure A-1 indicates that over ninety percent of the premature mortality related benefits of the final Tier 2/gasoline sulfur rule are due to changes in PM concentrations occurring above 10 $\mu g/m^3$, and around seventy-five percent are due to changes above 12 $\mu g/m^3$, the lowest observed level in the Pope, et al. study. Over fifty percent of avoided incidences are due to changes occurring above the $PM_{2.5}$ standard of 15 $\mu g/m^3$.

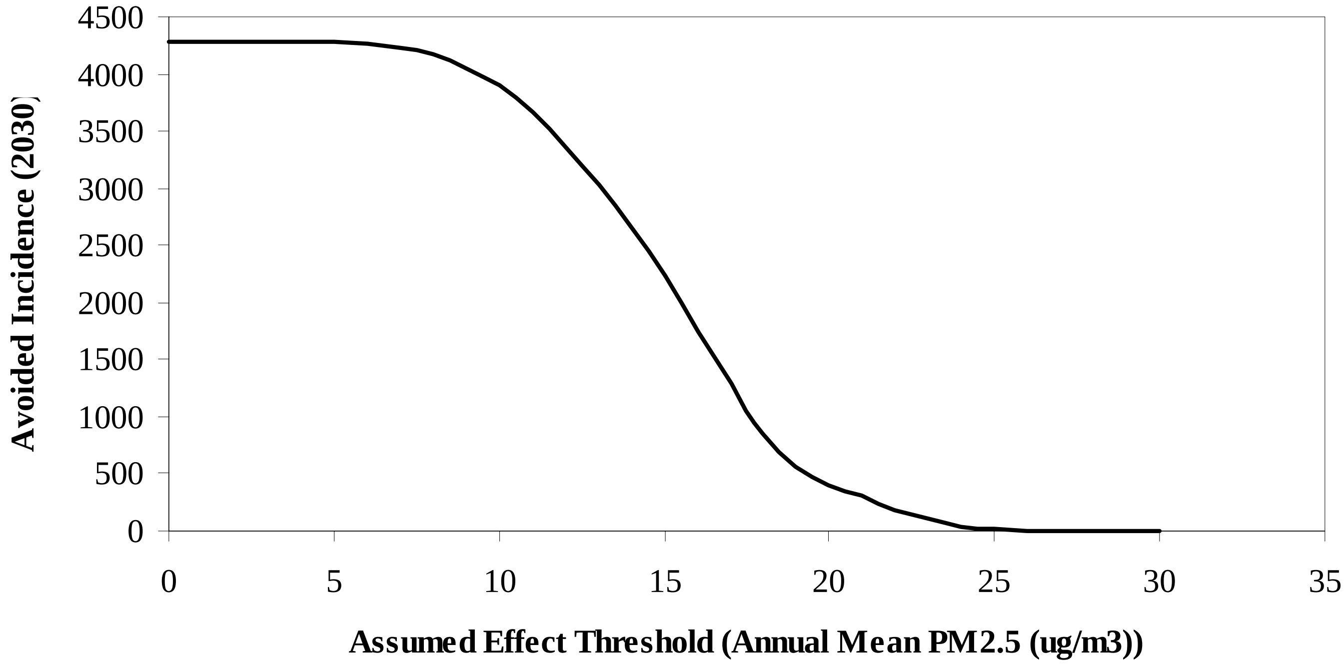

Figure VII-A-1
Impact of PM Health Effects Threshold on Avoided Incidences of Premature Mortality Estimated with the Pope Concentration-Response Function

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